Natural Environment Research Council, UK

British Geological Survey

Ministry of Agriculture & Natural Resources, Cyprus

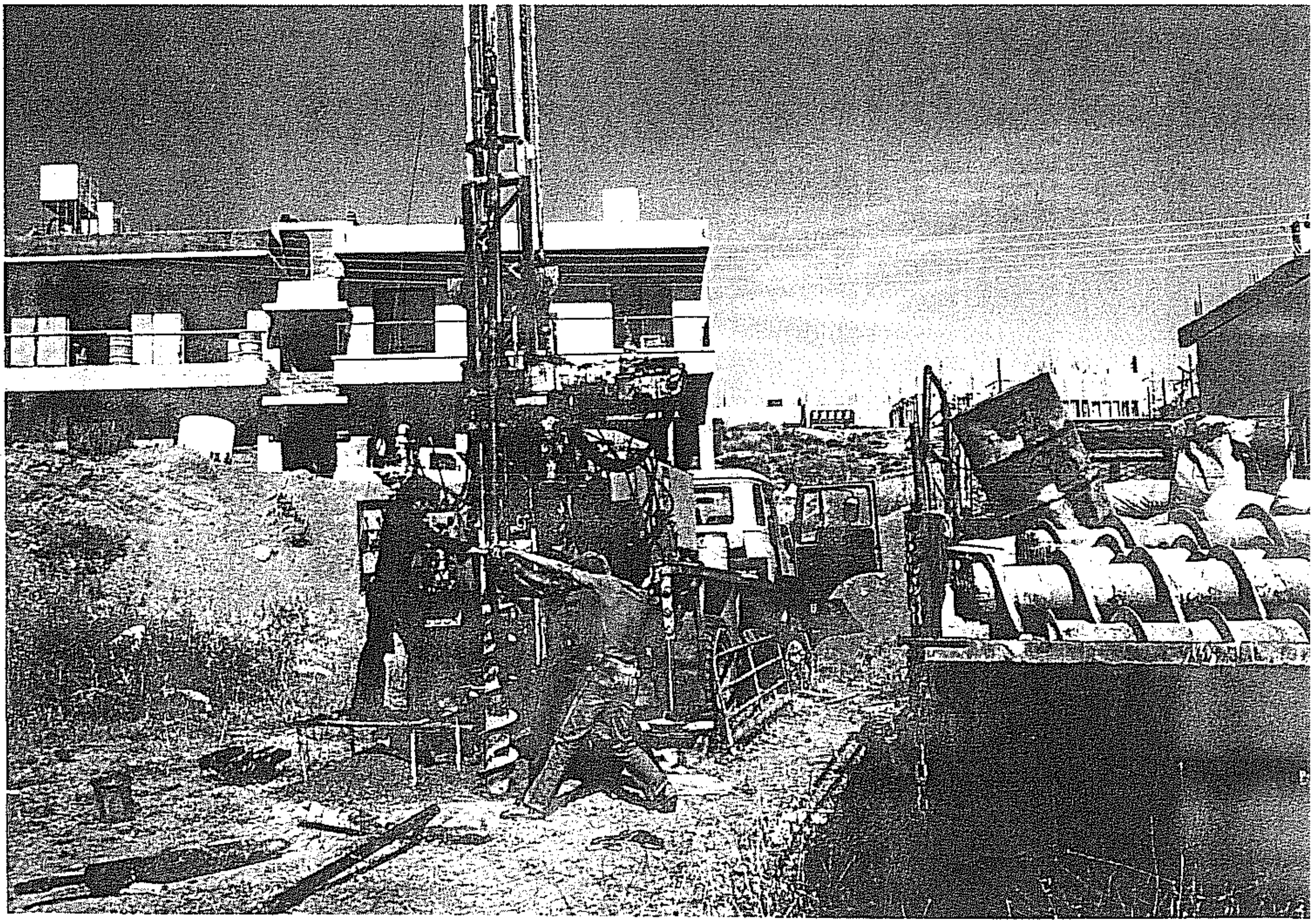
Geological Survey Department

ENGINEERING GEOLOGY & RESERVOIR
PROPERTIES RESEARCH GROUP
Report EGARP-KW/86/1

GSD Report
G/EG/12

GEOTECHNICAL PROPERTIES AND BEHAVIOUR OF PLIOCENE MARL IN NICOSIA, CYPRUS

P. R. N. Hobbs, G. Loucaides and G. Petrides



ENGINEERING GEOLOGY OF COHESIVE SOILS ASSOCIATED WITH OPHIOLITES
WITH PARTICULAR REFERENCE TO CYPRUS

British Geological Survey
Natural Environment
Research Council, UK

Geological Survey Department
Ministry of Agriculture & Natural
Resources, Cyprus

Report EGARP-KW/86/1
GSD Report G/EG/12

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

Geotechnical properties and behaviour of Pliocene marl in Nicosia, Cyprus

P. R. N. Hobbs, G. Loucaides and G. Petrides

Bibliographic reference

Hobbs, P. R. N., Loucaides, G., and Petrides, G. 1986. Geotechnical properties and behaviour of Pliocene marl in Nicosia, Cyprus: Engineering geology of cohesive soils associated with ophiolites, with particular reference to Cyprus. *Rep. EGARP Res. Group Br. Geol. Surv.*, No. EGARP-KW 86/1; *Rep. Geol. Surv. Cyprus*, No.G/EG/12.

Keyworth, Nottinghamshire British Geological Survey 1986
Nicosia Cyprus Geological Survey Department 1986

This report describes work carried out using funds provided by the Overseas Development Administration,U.K.

The cover photograph shows a Mobile 838 power auger of the Geological Survey Department,Cyprus taking undisturbed U100 samples of the Nicosia Marl at a new housing development in Anthoupolis,Nicosia.

EXECUTIVE SUMMARY

This report describes the results of a field and laboratory study to investigate and characterise the geotechnical properties and engineering behaviour of the Pliocene marls in greater Nicosia, south of the UN 'Green Line'.

Following a review of the literature and pre-existing data, the field survey undertaken included the logging of cut sections and excavations and the drilling of 11 augered boreholes to obtain undisturbed 100mm diameter samples for laboratory analysis and geotechnical testing. Standpipe piezometers were installed in the boreholes to monitor perennial water levels. Construction sites, damaged buildings and excavations were examined to ascertain whether the effects of surface and ground water, particularly with regard to swelling/shrinkage of the marl foundation, significantly contributed to foundation distress and excavation instability.

A full suite of geotechnical classification (index) tests, triaxial strength tests and consolidation/swelling tests were carried out in the laboratory. In addition, X-ray diffractometry and chemical analyses were undertaken and the results correlated with the determined geotechnical index parameters.

The range and areal distribution of those properties indicative of engineering problems is examined; in particular, plasticity, sulphate content, and montmorillonite clay content. A tentative classification of the marls is made based on visual description, geotechnical characteristics and mineralogical properties. It is shown that in many cases, visual description alone is an inadequate guide to engineering behaviour, as the 'marl' formation ranges gradationally from highly plastic clays, through marls and calcarenitic marls, to calcarenites. The transition between lithological type, which is invariably difficult to define in the field, results in an overlap of soil properties and engineering behaviour.

The effects of weathering and exposure to seasonal climatic changes are shown to be very important to shallow engineering works. An attempt to apply expansive soil models developed elsewhere to the current test data

was met with only limited success, and may be explained by differences in climate, lithological details and test methods employed.

Protection of open cuts in the marl is shown to be a necessary requirement during the construction phase to prevent moisture loss and slope failure in excavations where all but very short term instability conditions are required. In marls of high plasticity it is suggested that foundations be taken to depths of at least 4 metres in order to avoid the zone of seasonal moisture change and that bearing pressures do not fall below 200 kPa.

Particle cementation is shown to play an important role in the engineering behaviour of the marl but its effect is difficult to quantify in engineering terms.

ACKNOWLEDGEMENTS

The authors wish to thank the Director of the G. S. D. (Cyprus), Dr. Constantinou, and the Director of the B. G. S. (U.K.) for their permission to publish this report and the Overseas Development Administration for funding this project.

The authors wish to thank Mr. K. Solomis and the staff of the geotechnical laboratory at G. S. D., and the staff of the drawing office at the G. S. D., for carrying out the soils testing and final drawings, respectively. The authors are indebted to Dr. Morgan and Mr. A. Bloodworth of The Applied Minerology Unit (B. G. S.) for carrying out mineralogical studies. Special thanks are due to Mr. D. Entwisle for carrying out the swelling pressure and other tests and for his assistance in preparing the text.

CONTENTS

LIST OF FIGURES AND APPENDICES

APPENDICES

(1) 1.1. B. H. Log - description, SPT, Index, M/C, Triax, Photo-Log EG 20/83

1.2. Mineralogy test data

1.3. Swelling data sheet

1.4. Consolidation data

(2) 2.1. Chemical test profiles

2.2. Particle-size grading curves

2.3. e-log p' and M_v-log p' consolidation curves

2.4. Triaxial test results: stress-strain curves and Mohr-circle plots

2.5. Swelling pressure-time curves

2.6. Coeff. of secondary compression (c_α) v log p' curves

(3) 3.1. Water levels for boreholes EG 7/82 EG 18/82

3.2. e-log p' constructions - Casagrande & Schmertmann

3.3. Graphs of Surface Area v montmorillonite content and Surface Area v Liquid Limit

3.4. Graph of moisture content v Dry Density

3.5. Graph of moisture content v Depth

3.6. Graph of Plasticity Index v Sand-size content

LIST OF SYMBOLS AND ABBREVIATIONS

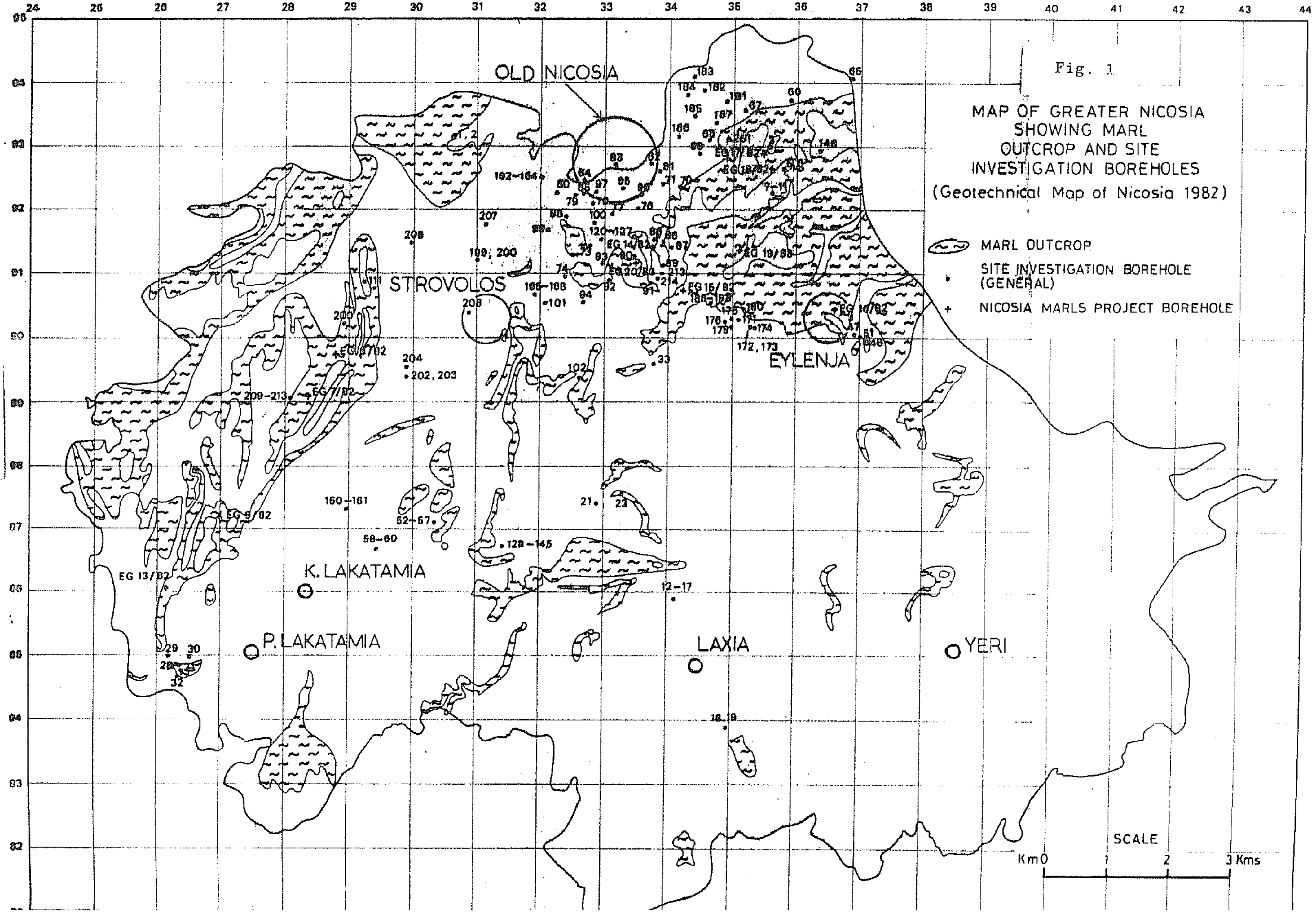
A	Activity $\left[A = \frac{P.I.}{\% CLAY}\right]$
Al.	Aluminium
A. M. U.	Applied Mineralogy Unit (B.G.S.)
b	width
B. F.	Backfill
B. G. S.	British Geological Survey
B. H.	Borehole
B. R. A. B.	Building Research Advisory Board (U.S.A)
B. S.	British Standard
B. S. C. S.	British soil classification system
^0C	centigrade
cc.	cubic centimetres
cm.	centimetre
cu.	undrained cohesive strength
C_v	coefficient of consolidation
Ca	calcium
CARB	Carbonate
calcar.	calcarenite
C_α	coefficient of secondary consolidation
$C_{\alpha s}$	coefficient of secondary swelling
Cc	compression Index
Cs	Swelling Index
C. B. R.	California Bearing Ratio
C. P.	Code of practice
C. M.	calcerenitic marl
dk.	Dark
d	Depth, thickness
e, e_o	Voids ratio, initial voids ratio
Eff.	Effective
E.G.A.R.P.	Engineering Geology and Reservoir Properties Research Group
E_{tan}/Ei/E	Initial tangent Young's Modulus
Fe	Iron
f/g	Fine-grained
fissd.	Fissured

ft.	Feet
Formtn.	Formation
g	Gram.
G.L.	Ground level
G.R.	Grid reference
Gs	specific gravity
G. S. D.	Geological Survey Department (Cyprus)
h	Height/thickness
Horiz.	Horizontal
Incr.	Increasingly
Km.	Kilometre
KN	Kilonewton
KPa	Kilopascal (=1KN/M^2)
l	litre
Lab	Laboratory
L. I.	Liquidity Index
L. L.	Liquid Limit
Lst.	Limestone
lt.	Light
M	Marl
M. or M/C	Moisture content (%)
m	Metre
Mangan.	Manganese
M. C.	Marly calcarenite
m/g	Medium-grained
ml.	millilitres
mm.	millimetres
MONT.	Montmorillonite
Mpa	Megapascals (=MN/M^2)
m_v	Modulus of volume compressibility
N	Newton
n	Number of samples (statistics)
Nat.	Natural
Nc	Bearing capacity factor (for cohesion)
O. C. R.	Overconsolidation ratio
p	Total overburden pressure
p'	Effective overburden pressure
Pa	Pascal (=N/m^2)

Pc'	maximum previous effective overburden pressure
pH	Hydrogen ion concentration
P. I.	Plasticity Index (P.I.= L.L. - P. L.)
P. L.	Plastic Limit
P. S. A.	Particle Size analysis
P. W. D.	Public Works Department Cyprus
Q. U.	Quick-undrained Triaxial test
r	Coefficient of correlation (statistics)
r^2	Coefficient determinism (statistics)
ref.	Reference
S	Degree of saturation (%)
S. A.	Surface area (mineralogy)
S. D.	Standard deviation (statistics)
Si	Silicon
Sl.	Slightly
S. M.	Sandy Marl.
S. P. T.	Standard Penetration test.
Sst	Sandstone
St	sensitivity
Su	Undrained shear strength
SW. PR.	Swelling pressure (alternatively Psw.)
t	Time
tr.	Trace
U4	4 inch diameter sampling tube
unif.	Uniform
U. S. C. S.	American Unified soil classification system
U. U.	Unconsolidated, undrained Triaxial test
v	versus
v.	very
vert.	vertical
w.	width
W. D. D.	Water Development Department
weathd.	weathered
W/T	Water table (depth of)
$\bar{x}$	Mean (statistics)
yr.	Year
ϕ	Diameter

ϕ_u	Undrained angle of internal friction
ϕ_r	Residual angle of internal friction
ϕ'	Effective angle of internal friction
γ_b	Bulk unit weight
γ_d	Dry unit weight
γ_{sub}	Submerged unit weight
σ_z	Vertical stress

Fig. 1



MAP OF GREATER NICOSIA
SHOWING MARL
OUTCROP AND SITE
INVESTIGATION BOREHOLES
(Geotechnical Map of Nicosia 1982)

Fig 1

INTRODUCTION

This report describes the results of work carried out in Nicosia during 1982-1983 and forms the first phase of a four-year research programme funded by the Overseas Development Administration into the engineering geology of cohesive soils associated with ophiolites. The research programme developed directly from the publication, in April 1982, of the Geotechnical Map of Nicosia and accompanying report which presented a 'regional' geotechnical assessment of all the soils and rocks in the greater Nicosia area. The current study examines the Pliocene Marls of Nicosia in detail and, as with the earlier work, has resulted from collaboration between staff of the British Geological Survey and the Geological Survey Department of Cyprus.

A total of 11 boreholes have been drilled and sampled with U4's and tested in situ with S.P.T.'s. A full suite of geotechnical and selected mineralogical tests were carried out at 1 to 2 metre intervals. Two of these boreholes (EG 19/83 and EG 20/83) have provided continuous U4 samples which have been split and examined for weathering and structural features. Nine boreholes have had standpipe piezometers installed and water levels are being monitored.

Geotechnical testing has been carried out at the soils laboratory of the Engineering Geology Unit of the G. S. D. in Nicosia by technical staff of the G. S. D. Chemical tests have also been carried out at the G. S. D.'s own laboratories in Nicosia. Swelling-pressure, ring shear and high pressure consolidation tests have been completed by the Engineering Geology Unit of B. G. S. in Keyworth and mineralogical analysis by the Applied Mineralogy Unit of the B. G. S in London.

This report aims to classify the marls of Nicosia in terms of their geotechnical and mineralogical properties and their occurrence in situ, as this relates to their engineering behaviour. Particular attention has been paid to the swelling and compressibility characteristics of the marls, which are of some concern locally.

Current building practice in Nicosia is for all structures,both domestic and commercial and both low and high rise, to be built using a reinforced concrete frame with unstressed hollow-brick filling, founded on either pad or strip footings linked by ground beams. Foundations are frequently designed to take higher loads as a result of extra storeys which may, or may not, be added at a later date. This fact may be largely responsible for some instances of failure due to heave. Footings are generally cast in pits at a depth of between 2 and 4 metres in marl; this being taken as the depth below which no seasonal moisture variation takes place. Some measures, such as the coating of excavation walls with plaster or polythene sheeting, and blinding with concrete are used to prevent spalling and collapsing of the walls due to drying and, in the case of foundation surface, to protect from moisture gain or loss, but these are not rigorously applied and may not always be effective. Frequently, excavations are open for long periods to construction. A combination of shallow foundations, often of poor quality in the case of older buildings, and the swelling of marl consequent upon infiltration, leaking pipes, cess-pits etc. has led to some structural distress and failure in the past. Piling is uncommon in Cyprus due to the lack of equipment and expertise. The design of foundations in marl is usually derived from previous experience and site investigation in the case of government buildings or large commercial structures. A site investigation is carried out either by the G. S. D., W. D. D. and P. W. D. or by overseas contractors, there being no specialist commercial firms in Cyprus. The usual methods of investigation are S. P. T.'s, index testing, QU Triaxial and oedometer consolidation testing. Chemical tests are also carried out by G. S. D. The Public Works Dept. laboratory is capable of such tests as C. B. R. compaction.

The marl in Nicosia is for the most part of Pliocene age and belongs to the Nicosia Formation. Within the overlying Athalassa Formation (early Pleistocene Age) there are bands of marl occuring as thin intercalations in a dominant calcarenitic sequence.

The Pliocene marl, which is the main subject of the present work, is characteristically grey when fresh and khaki when weathered and it is a silty clay or a clayey, sometimes sandy, silt. Often there is interfingering of marl beds with calcarenite beds and intermediate material referred to as marly calcarenite and calcarenitic marl.
We shall in this report describe the properties of the marls in their

SUMMARY OF GEOLOGY IN NICOSIA STUDY AREA (derived from DUCLOZ 1964)

HOLOCENE		RECENT	Gravels, silts and loams forming 2 terrace levels - the first stands 3-4m above present river bed. The more recent stands 1-2m above river bed.
		XERI ALLUVIUM	pale brown masive to poorly stratified marly silts and gravels (thickness up to 20m) from flat tracts above present flood plains (e.g. Pedieos valley where alluvium is 6 to 8m above river. Xeri alluvium was deposited on eroded weathered (redsoil) Laxia Gravels.
PLEISTOCENE	GAMBLIAN PLUVIAL	LAXIA GRAVEL	Thin blanket of loose poorly-rounded gravel (thickn.: 1-3m) havarised at top & capped by red soil. Similar to Kambia & Kantara gravels cuts into them. Alluvial facies exists E of Xeri - this is yellowish silty marl and current-bedded sst, (up to 15m thick.)
	KANJERAN PLUVIAL	KAMBIA GRAVEL	Lower level than Kantara. Thickn. 1-4m (max 10m). Type loc. Kambia dip 1^{o}-3^{o} N. & N.E. thickest to east of Pera & S.W. of Xeri. Deposited in Kanjeran pluvial. Unsorted poorly rounded sub-angular frags. of igneous - cobbles, boulders. Top is thin red clay on havara. On left bank of R. Alikos→sorted, rounded with marl.
	KAMASIAN PLUVIAL	KANTARA GRAVEL	Thin blanket of cobble and boulder uncomformably overlying the Apalos, Kakkaristra, Athalassa & Nicosia Formations. Dip 1-3^{o} to N.E. Generally 2-3m thick (max. 6m). Usually covered by thin fossil reddish-brown soil (lateritic). Unsorted igneous grav. in sandy & clayey matrix.
	SICILIAN	APALOS FORMATION (CONTINENTAL)	Thickn. 6m. to 36m. (max. 65m). Type loc. Apalos Hill (S.W. of Laxia). A marsh or flood plain deposit - well stratified, near horiz. siltstones, conglomerates greywackes and marls of freshwater origin. Dominant deposit is brown-reddish-or yellowish grey (mottled with reddish dominating in upper part) clayey to marly, massive to poorly stratified siltstone. At the base siltstones intercalate with grey silty marl & thin greywacke. At upper part siltstones intercalate with stratified gravel & conglomer. (Channel filling). Well exposed at Kantara Hill and W. of Lakatamia (prev. mapped as "Marine Fanglomerates").
	CALABRIAN	ATHALASSA FORMATION (MARINE)	Max dip 3^{o} type loc. Liondari Hill thickn. 6m (Nicos.) to 50m (S.E. of Laxia) A series of low lying fossil, current-bedded sandstones detrital limestones & detrital limestones and stratified silty marls. Largely marine but grades laterally into terrestrial, lacustrine and brackish deposits to the South. Main deposit m-c fossilif. current-bedded calcarenite interbedded with sandy fossilif. marls. Calcarenites are v. similar to those of Nicosia Formation but somewhat coarser grained. May contain conglomerates of Nicosia calcarenite and igneous gravels. Locally calcarenites grade into fossilif. detrital Lst. (with impure chalk S of Laxia). To south calcarenites predominate over marls. In Engomi and Peerneraes base of Athal. is fossil marl and pebbles of reworked calcar.
		KAKKARISTRA FORMATION (CONTINENTAL & FRESHWATER/ BRACKISH)	thickn. 14m to 26m non-fossilif. grewackes siltstones & conglomerates; minor intercal. of fossilif. marls with greywackes. Minor intercal. of lacustrine Lst. near top. Generally formation is marine/brackish. Grades laterally into Athalassa E & N of Laxia & at Nicosia airport, includes so-called "Marine Fanglomerates" & "Pliocene Marls". Contains horizons of weakly consolidated igneous conglomer or gravel (often current-bedded) - Probably beach deposit (quarried S. of Laxia).
	PLIOCENE	NICOSIA FORMATION	Formed on a shallow (5-10^{o}) syncline E-W axis. There are few minor faults; main joints are (1) NNW (2) NNE & (3) ENE. Three main units are seen at type locality to S. of Nicosia:- a) marl with thin calcarenite intercalations (fossilif. bed to South) becoming f-g soft marly grewackes & siltstone with thin concretions on top. b) Calcarenite unit - diminishing southward. c) Marly basal unit becoming siltstones & calcarenites to west of Nicosia. Top of the Formation becomes sandier to the S. (consisting of 15 to 20 m marly greywackes and siltstones intercalated at top with sandy facies containing fossil 'Ostrea' bed.).

Fig.2

Fig. 2 SUMMARY OF GEOLOGY IN NICOSIA STUDY AREA (from Ducloz, 1964)

1. GEOLOGY

1.1. Summary of geology

Deposition of the rocks in the study area took place in the environment of a fault-controlled subsiding basin. Faulting of the Troodos volcanic basement beneath the Mesaoria plain resulted from the final late Miocene emplacement of the Kyrenia range to the North. Kythrea and Ovgos faults (E-trending) divided the plain into sub-basins undergoing differing sedimentation in the Pliocene (Baroz and Bizon, 1974). Increasingly arenaceous deposits are encountered southward towards Troodos where there is overstepping onto the Troodos basement.

The Nicosia and Athalassa formations are predominantly arenaceous shallow marine sediments which are laterally variable and as yet little known (Robertson, 1977). The onset of the Pleistocene saw drastic uplift (2,000 m) of Troodos which initiated rapid denudiation releasing a flood of immature sediment, the "Fanglomerates". Alluvial fans spread into the Mesaoria sea forming the marine Fanglomerates; Continental Fanglomerates coarser and less sorted, were also deposited. By the end of the Pleistocene the sea had been displaced to leave the present coastline.

The Late-Glacial and Post-Glacial have been times of increasing desiccation (Everard, 1953). The present climate is semi-arid and the Nicosia area is devoid of perennial rivers. The development of calcareous duricrust over large parts took place largely in former wetter periods, the topography of which is preserved in the contours of the duricrust surface. Erosion has broken this down into the more angular plateaux or mesas of the semi-arid environment seen today (see Fig. 3). The desiccation has generally had a stabilizing effect on the otherwise unconsolidated sediments. The main lithological features of the Mesaoria group are given in Fig. 2.

1.2. Nicosia Formation

Early workers (Gandry 1862, Russel 1882, Reed 1930 and 1935, Henson et al 1949) recognized the marl and calcarenitic sequence of the Nicosia area as part of the Pliocene sequence and with increased knowledge from field and palaeontological work this sequence led to recognition of two Formations (Ducloz 1964) the Nicosia Formation (Pliocene) and the overlying Athalassa Formation (Pleistocene with an equivalent Kakkaristra Formation representing facies variation).

The Nicosia Formation in the type-locality southeast of Nicosia consists of a series of fossiliferous silty grey marls and fine-grained calcarenite which contains towards its middle part a thick lenticular body of yellow-brown, porous, coarse grained calcarenite. The base of the formation is largely concealed under the Recent alluvium of the Pedieos River but the total thickness of the formation can safely be estimated to be about 800 metres, a figure which is quite in accordance with the thickness recorded in a borehole (Xeri Borehole) drilled almost in the centre of deposition of the formation. The calcarenite member, which reaches a maximum thickness of about 250 metres, outcrops directly south of Eylenja and forms a prominent scarp south of Nicosia. The outcrop area is dotted by numerous abandoned quarries from which the building stones of the old city of Nicosia were extracted. The calcarenite horizon locally divides the formation into three members: a lower predominantly marly basal member, a middle calcarenite member, and an upper member consisting of marls intercalated with thin beds of calcarenite.

The Formation is overlain uncomformably by the Athalassa Formation.

Descriptions of the Nicosia Formation have often been restricted to the calcarenite member which is well exposed, whereas the marly members, which are poorly exposed have, to a degree been overlooked.

However with the expansion of the suburban areas of Nicosia and the need of construction in areas dominated by marly outcrops the significance of the marls in terms of foundations for low and high rise buildings increased together with the need for a better understanding of the distribution, and geotechnical behaviour of this soil type. Detailed geological observations (Ducloz 1964) are now being supplemented with geotechnical investigations and studies of the Pliocene Marl and all the results are summarized in the present report.

The Nicosia Formation of the type-area with its conspicuous middle calcarenitic member grades southward into a sequence of marly siltstones and silty marls intercalated with only a few beds of fine-to coarse-grained clastics, such as marly greywackes, well-rounded conglomerates and locally rare beds of the sequence and occur in thin lenticular bodies. The dominant rock-type of the southern facies of the Nicosia Formation is a medium-grey, marly siltstone which is usually referred to in the literature as a marl. This sequence is massive or poorly stratified and is composed of very small angular grains of pyroxene, plagioclase , calcite and magnetite. When dry it disintegrates easily in water. It is fossiliferous and contains, in places, many well-preserved shells of marine bivalves and gastropods.

The southern predominantly silty and marly sequence of the Nicosia Formation generally rests on the underlying Miocene or Eocene sediments with any intervening basal conglomerate or sandstone. The contact is an angular unconformity.

In a few places, however, there is either at the base or close to it some coarse deposits such as conglomerates and coarse-grained sandstones. These accumulations, which may reach as much as 50 metres in thickness were observed south of Pera, southwest of Politiko and east and south of Aredhiou villages. They occur as tongues extending in a north-south direction and are probably related to old deltas of rivers draining the Troodos and which were flowing more and less at the emplacement of the present drainage.

Apart from the basal conglomerate the monotonous series of marly siltstones and silty marls of the southern facies of the Nicosia Formation is broken by four thin intercalations of coarser grained deposits. These intercalations are of localised lateral extent and cannot be regarded as members. The lowest occurs some 220 metres above the base of the formation and consists of a 6 to 15 metre bed of fine-to medium-grained, soft, marly greywacke which is apparently a beach deposit. Higher up in the series, about the middle part of the formation, there is a bed of wider extent and of coarser character than that just described. It is formed by marly greywackes, thin stringers of conglomerates and in places by a calcarenite similar to the typical calcarenite of the Nicosia area but where ripple-marks were observed. Components of the conglomerates show that the source of the material was also the Troodos Massif. The maximum thickness of this coarse horizon which outcrops east and west of Psomolophou is only 10 metres. In the upper part of the formation, some 180 metres above the coarse horizon just mentioned, there is a conspicuous lenticular intercalation of rudaceous material and greywackes.

The top of the Nicosia Formation, in the southern part of the studied area, shows a definite and more general increase in sandy material compared to the lower part of the formation. It consists of about 18 metres of grey fine-grained stratified, soft, marly greywackes with thin, hard, calcareous, nodular concretions, tabular or ellipsoidal in shape. Intercalated with these greywackes are a few thin rudaceous beds observed below. The sandy top of the formation is very rich in plant remains, but rather poor in fossils.

The Nicosia Formation has been only very slightly folded and forms, in the area of investigation, a wide syncline, with an axis running parallel to the margin of the Troodos, that is N 75W. This axis passes about 1 km north of Kato Lakatamia and Laxia. Dips on both limbs of this syncline are low and usually from 5 to 10 degrees although higher dips, up to 20 degrees were observed locally. The formation is cut by numerous joints pertaining to three main sets of fractures which align roughly NNW, NNE and ENE. The two former are the more prominent. Only a few faults were recorded, they belong to one or the other set of fractures just mentioned. Displacement along these faults is very small and never exceeds a few feet. It seems that there is a relation between the fracture pattern observed in the Pliocene sediments and the system of fractures which cut through the Troodos massif.

The top of the Nicosia Formation shows evidence of an emergence such as lamellibranch borings (HENSON et al. 1949) worm borings (SCHMIDT S. 1962) and a well-defined angular unconformity usually seperates the formation from the overlying Athalassa or Kakkaristra formations. South of Nicosia the surface separating the two formations is uneven and displays a low relief suggesting that the period of erosion which took place before the deposition of the overlying Athalassa formation was not of long duration.

1.3. Athalassa Formation

The first good description of the formation was given by Henson et al (1949). The formation is described as a series of low-lying fossiliferous, current-bedded sandstones, detrital limestones and stratified silty marls overlying the Nicosia or older formations in the Mesaoria snd coastal areas. Liondari Hill, a conspicuous flat-topped mesa, southeast of the Government Stock Farm at Athalassa is taken as type locality. In this locality, there is some 45 metres of Athalassa sediments resting with an angular unconformity over the marls and calcarenites of the upper part of the Nicosia Formation. The Athalassa Formation is a distinct unit (Ducloz, 1964) even in the centre of deposition but its facies vary considerably southwest and west of the type area. The marine Athalassa Formation, characterised by its buff, fossiliferous beds grades laterally into an heterogeneous sequence of terrestrial, lacustrine, brackish and marine strata which were mapped previously in part, as marine Fanglomerates and, in part, as marine Pliocene marls (GASS 1960; BEAR, 1960). This mixed continental, brackish and marine deposit is named the Kakkaristra Formation.

The Athalassa Formation, in the type area consists of several beds of medium-to coarse-grained, fossiliferous, current-bedded calcarenite interbedded with sandy, fossiliferous marls. The calcarenites are very similar to the calcarenites of the Nicosia Formation, although in general they are coarser grained. In places they contain lenticles of conglomerates made up of poorly rounded pebbles derived from the calcarenites of the Nicosia Formation and of well rounded pebbles of igneous rocks of the Troodos Massif. In some specimens of the Athalassa calcarenite the proportion of detrital parts is higher than in the typical Nicosia calcarenite.

Ripple-marks were observed occasionally on stratification planes of the Athalassa calcarenites. Their predominant alignment is about N70E but in one place it swings towards the north with a strike of N30E.

The proportion of calcarenites to marls varies from place to place. In the type area the calcarenites and marls are evenly represented but southward, in the Yeri area and southeast of Laxia the calcarenites predominate over the marls and in places, form almost the bulk of the formation.

The Athalassa Formation is horizontal or is tilted with gentle dips which rarely exceed 3°. The formation is much less jointed than the underlying Nicosia Formation and the principal joint sets trend NNW and NNE.

The contact between the Athalassa Formation and underlying Nicosia Formation is an angular uncomformity with a difference of dip between 5 to 10 degrees. However, in a few places, near Laxia for instance, both formations are flat-lying but the contact, is disconformable. In the area directly south and west of Nicosia the Athalassa Formation transgresses deeply over a truncated sequence of the Nicosia Formation.

In the type-locality, the Athalassa Formation is overlain unconformably by the Kantara Gravel, a younger Pleistocene unit, but westward near Strovolos and Engomi it is overlain conformably by the freshwater brown silty marls and clays of the Apalos Formation.

The thickness of the Athalassa Formation ranges from 6 metres directly south and west of Nicosia, to about 45 metres in the type area and southeast of Laxia.

The Athalassa Formation is very fossiliferous but there are still some uncertainties about its age. REED (1930, 1935) did not recognize the formation as a separate stratigraphical unit; but collected macrofossils which from his descriptions, come from the Athalassa Formation. At the type locality of the Athalassa Formation fossils from the middle part of the formation are definitely attributed by REED to the Astian whereas fossils collected in the upper part of the formation are considered as possible Calabrian. South of the type locality, on the Eylenja-Yeri road, a rich macrofauna from beds near the base of the Athalassa Formation is again reported to the Astian. Fossils, also found in the lower part of the formation, are attributed to the Astian or possibly to the Calabrian. The only unquestionable Calabrian fauna reported by REED from the Athalassa Formation, in the Mesaoria, comes from a small conical hill near Pyroi.

Thus the Athalassa Formation according to REED's findings is Pliocene (Astian) and extends in the Calabrian. HENSON et al. (1949) give a short list of fossils from the Athalassa Formation a Calabrian age but this is given with a question mark. Bones of mammals found in the Kakkaristra Formation, a freshwater-brackish equivalent of the Athalassa Formation, will confirm that the age of the Athalassa Formation is definitely younger than the Pliocene and very likely Calabrian.

1.4. Apalos Formation

The Apalos Formation (Ducloz, 1964) is a series of near-horizontal siltstones, conglomerates, greywackes and marls of freshwater origin conformably overlying the Kakkaristra or the Athalassa Formations. It is overlain unconformably by a thin veneer of coarse gravel, the Kantara Gravel. The formation is, as a whole, well stratified and obviously has been deposited in an aqueous or subaqueous environment. Except for reworked foraminifera the formation is notably barren of fossils. It is well exposed at Kantara Hill and west of Kato and Pano Lakatamia. It had been previously mapped as Marine Fanglomerates (Bear, Gass, 1960).

The dominant and most characteristic sediment of the Formation is a brown to yellowish grey clayey to marly to poorly stratified siltstone. It is frequently mottled with different hues of brown and grey. The brown colouration increases noticeably in intensity in the upper part of the formation where even some reddish brown colours are noted. The siltstones are intercalated toward the base of the formation with beds of grey silty marl, and locally with thin beds of greywackes; whereas in the upper part of the formation there are several intercalations of stratified gravel and poorly consolidated conglomerate. These rudaceous beds increase progressively in number, thickness and coarseness towards the top of the succession.

1.5. Younger Superficial Deposits

Overlying the Nicosia, Athalassa and Apalos Formations there is a succession of generally thin igneous gravels which cover large tracts of the study area. These are seen capping the mesas and frequently occur as a cemented duricrust, (Chapman, 1974). The surface gravels weather to form a thin residual soil. The Kantara gravel is found capping the hills of the Apalos formation to the North West and notably to the East and South East of Strovolos. The Kambia gravels cover a large area of over-lying ground from Strovolos to Xeri. The Laxia gravel is found in a broad band immediately West of the Kambia gravel deposit and also to the West and South East of Laxia where is overlies the Kakkaristra and Athalassa formations. Kambia and Laxia gravels are found infilling channels eroded in the Kantara gravel.

The Xeri Alluvium occupies the Pedieos river notably at Dheftera, Strovolos, and to the North East of Nicosia town. Other alluvial deposits are of more recent origin and form the lower terraces.

The ancient walled town of Nicosia stands in the Pedieos valley at the point where the river broadens and veers Eastward. To the South the distinctive E-W scarp of the Nicosia formation calcarenite rises sharply from the marl plain and is particularly prominent at Eylenjia (see Fig. 3). This calcarenite has provided the bulk of Nicosia's building stone, as evidenced by numerous quarries.

2. SAMPLING AND TEST METHODS

2.1. Sampling Methods

A total of 11 boreholes were sited to sample the main marl outcrops in in Nicosia and the greater Nicosia area (see Fig. 1). A list ofthe types and quantity of tests carried out is given in Fig. 4. A total of 44 samples were taken for testing. Boreholes were drilled using the G. S. D.'s Mobile 838 power auger and samples were recovered by pushing a U4 (0.1 x 0.45 m) sample tube into the case of the augered hole. In most cases the U4 was filled by applying continuous hydraulic pressure. In a few cases hammering was required. In the intervals between U4 sampling, SPT's using a split-spoon head were carried out. The holes were drilled to depths of between 6 m and 13.5 m with the exceptions of EG 19/83 and EG 20/83 which were deeper. On completion, each borehole was fitted with a PVC standpipe piezometer set in a 1 m gravel pack and sealed with bentonite. The nine holes drilled during May and June, 1982 (i.e. boreholes EG 7/82 → EG 18/82) have had water-levels monitored by G. S. D. staff at monthly intervals (see Appendix 3.1.

Moisture-content sub-samples were taken on site and U4 samples sealed with hot paraffin-wax and grease and despatched to the G. S. D.'s soils laboratory for testing. In the laboratory samples were extruded from the U4's using a power-driven machine and sub-samples for Triaxial, consolidation and Index testing removed and trimmed as required. Sub-samples were also taken for despatch to B. G. S. Keyworth; these were wrapped in aluminium foil and then coated in wax. Additional moisture content determinations were made after extrusion of the core.

2.2. Testing Methods

2.2.1. Triaxial Tests

The Triaxial tests carried out at the G. S. D. were of the Multi-stage (3 stage) unconsolidated, undrained type (UU) without pore-pressure measurement. Samples, nominally 100 mm x 200 mm, were tested on Wykeham-Farrance cell using a compressed air system. Results, taken from Mohr-circle plots, are given as ϕu and Cu or as estimated shear strength

FIG.4

RECORD OF LABORATORY TESTS

BOREHOLE NO.	DEPTH (m)	MOISTURE CONTENT	DENSITY	SPECIFIC GRAVITY	ATTERBERG LIMITS	PARTICLE SIZE	FREE SWELL	CONSTANT VOL. SWELL	CHEMICAL TESTS				X-RAY DIFF. (BGS)		TRIAXIAL (UU Test)	CONSOLIDATION
									Carbonate		Sulphate	Montmorillonite	Surface Area (Mont.)	Others		
									GSD	BGS						
EG 7/82	2.0-2.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	4.0-4.5	0			0	0	0		0		0	0	0	0		
	6.0-6.5	0			0	0			0		0	0			0	
	11.0-11.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	13.0-13.5	0	0	0	0	0	0		0		0	0	0	0	0	0
EG 8/82	2.0-2.5	0	0		0	0	0	0	0	0	0	0	0	0		
	3.0-3.5	0	0		0	0	0		0		0	0				
	4.0-4.5	0	0	0	0	0		0		0			0	0		0
	5.0-5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EG 9/82	2.0-2.5	0			0	0	0		0		0	0				
	3.5-4.0	0			0	0	0		0	0	0	0	0	0		
EG 13/82	2.0-2.5	0			0	0	0		0		0	0				
	3.0-3.5	0			0	0	0		0		0	0				
	4.0-4.5	0			0	0	0		0		0	0				
EG 14/82	2.0-2.5	0	0	0	0	0	0	0	0	0	0	0	0	0		0
	3.0-3.5	0	0	0	0	0	0		0		0	0			0	0
	4.0-4.5	0	0	0	0	0	0		0		0	0			0	
	5.0-5.5	0	0	0	0	0	0	0	0		0	0				
	6.0-6.5	0	0		0		0	0	0	0	0	0	0	0	0	
	7.5-8.0	0	0	0	0	0	0	0	0		0	0				0
	9.5-10.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11.0-11.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
EG 15/82	3.0-3.5	0			0	0	0		0		0	0	0	0		
	7.5-8.0	0	0	0	0	0	0		0		0	0	0	0		0
	9.5-10.0	0	0	0	0	0	0		0		0	0	0	0	0	0
EG 16/82	2.0-2.5	0			0	0	0		0		0	0	0	0		
	4.0-4.5	0							0		0	0	0	0	0	
	5.0-5.5	0							0		0	0	0	0	0	
	6.0-6.5	0							0		0	0	0	0	0	0
EG 17/82	3.0-3.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	4.0-4.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	5.0-5.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	6.0-6.5	0	0	0	0	0	0	0	0		0	0	0	0		
EG 18/82	3.0-3.5	0	0		0	0		0		0			0	0		
	4.0-4.5	0			0	0				0			0	0		
	5.0-5.5	0	0		0	0		0								
	7.5-8.0	0	0	0	0	0										0
	9.5-10.0	0	0		0	0									0	
	11.0-11.5	0	0		0	0		0		0			0	0	0	
EG 19/83	17.0-17.5 (blue clay)				0	0										
	17.0-17.5 (black clay)				0	0										
	GREY CLAY				0	0										
	BROWN CLAY				0	0										
EG 20/83	13.0-13.5	0														0 (two high load tests)
	14.5-15.0 (grey clay)					0										

Fig. 4 RECORD OF LABORATORY TESTS

(Su) at total overburden pressure, calculated using the Mohr-Coulomb criterion. Initial tangent elastic moduli (E_{tan}) have also ben calculated.

2.2.2. Consolidation Tests

Consolidation tests were carried out at the G. S. D. using 70 mm x 19 mm disc specimens in a single Wykeham Farrance rear-loading oedometer. Five loading and two unloading stages of 24 hours each were used to produce the e-logp′curves. Values of Modulus of Volume Compressibility (mv), coefficient of consolidation (C_v), Compression Index (Cc), Swelling Index (Cs) and coefficient of Secondary Swelling ($C\alpha s$). Maximum previous over-burden (Pc) and thus the Over-Consolidation ratio (O. C. R.) have been calculated using the Casagrande construction, whilst the Schmertmann construction the 'field' compression/rebound lines (see App. 3.2). In addition, two special high-pressure, double-unloading, consolidation tests have been completed at B. G. S., reaching pressures of 32 MPa (32,000 KN/m^2).

2.2.3. Index Tests

Determinations of moisture content (m), Liquid Limit (L.L), Plastic Limit (P. L.), Specific Gravity (Gs) and Particle-Size were made at G. S. D. according to British Standard B.S. 1377 (1975); the Casagrande apparatus being used for the Liquid Limit test (Test method 2B, B.S, 1377, 1975), and the hydrometer method for the particle-size analysis (Test method 7D, B.S. 1377, 1975). In addition values of Bulk Density (γ_b), Dry Density (γ_d), and Degree of Saturation (S) were determined from Triaxial and consolidation specimens.

2.2.4. Chemical Tests

Determinations of total carbonate content, total sulphate content (both acid soluble and water soluble), montmorillonite content and Free Swell (both 1 hr and 24 hr tests) were made by the Geochemical Unit of the G.S.D. Montmorillonite content was found using the methylene-blue test. Free-swell was found by drying and crushing and weighing the sample then measuring the % expansion in distilled water; results are quoted at particular moisture contents. This method approximates to that suggested by Gibbs and Holtz (1954).

2.2.5. Swelling Pressure Tests

Swelling Pressure tests were carried out at B. G. S. on selected samples. These were oedometer-type disc samples (70 mm x 19 mm) in a standard oedometer cell adapted to fit a 10kN Triaxial load frame. The test method is described in Hobbs & Horseman (1983) and incorporates an electronic feedback system to eliminate swelling strain and thus ensure accurate measurement of the swelling pressure development consequent upon immersion of the sample in distilled water. Specimens were stored in a humidity/temperature controlled room and tested at 'natural' moisture content. A series of multiple swelling pressure tests at different moisture contents were made to study the effects of drying-out on swelling.

2.2.6. Mineralogical Tests

Mineralogical analysis was made by the Applied Mineralogy Unit of B. G. S. with 25 samples of marl. The results are given in AMU Report 83/10 and summarized in Appendix 1.2. The samples were examined using x-ray diffractometry (Philips PW 1050, Co - K_α radiation) on randomly oriented, air-dried material hand-crushed to minus 100 mesh. The phases identified are given in Appendix 1.2. In addition, quartz contents were calculated by comparison with quartz peak intensities of artificial mixtures. Thermogravimetric analysis was used to determine total carbonate content (maximum) (CO_2 at 25 ml/min and 50° c/min.) based on calcite weight loss. Surface Area (S.A.) measurements in m^2/g were made using the ethylene glycol monoethyl ether (EGME) method (see Georgiou & Morgan, 1979). Montmorillonite content was calculated from values of S.A. taking a value of 800 m^2/g for pure montmorillonite.

2.2.7 Residual Strength Tests

Three residual strength tests were made at B.G.S., Keyworth, using a Bromhead ring-shear apparatus. Measurements of residual shear angle (ϕr^o) were made at various normal loads on two samples of grey marl from borehole 7/82 and one sample of grey marl from borehole 14/82.

3. GEOTECHNICAL TEST RESULTS

3.1. Index Tests

3.1.1. Atterberg Limits

The results of Liquid and Plastic Limit tests are given in Appendices 1.1 and 3.6. and also in the form of a Casagrande Plasticity Chart in Fig. 5. Liquid Limits lie in the range 38% to 101% ($\bar{x}$ = 75.8, SD = 15.3, n = 43). Plastic Limits lie in the range 10.7% to 43.7% ($\bar{x}$ = 29.2, SD = 7.1, n = 43). these results place the marl clearly in the CH or highly plastic clay group of the USCS classification (see Section 6). Five samples lie below the 'A-line' (P.I. = 0.73 (L.L.-20)) in the OH, i.e. organic, group. Two samples lie in the CI, i.e. intermediate plasticity, group. The Atterberg Limits exhibit a statistical distribution close to that obtained for 178 samples described in Hobbs & Loucaides (1982) as part of the Geotechnical Map of Nicosia database. Liquidity Indices (L. I.) lie in the range -0.4 to +0.4 ($\bar{x}$ = 0.014, SD = 0.2, n = 39). The highest values of Liquid Limit (>90%) are recorded in boreholes EG 9/82, 17/82, 18/82 and 19/82.

3.1.2. Unit Weights

Bulk Unit Weight and Dry Unit Weight have been measured on 27 samples. Dry Unit weight lies in the range 1.31 to 1.67 g/cc ($\bar{x}$ = 1.44, SD = 0.08 , n = 27); Bulk Unit weight lies in the range 1.59 to 1.96 ($\bar{x}$=1.85, SD = 0.075, n = 27) and Specific Gravity lies in the range 2.58 to 2.78 ($\bar{x}$ = 2.68, SD = 0.05, n = 20). These results (see Appendix 1.3) agree with those quoted in Hobbs & Loucaides (1982) and in Anon, (1972). Borehole 14/82 exhibits a steady decrease of Dry Unit Weight with depth between 3.0 m and 10.0 m. All boreholes show downward decreasing Dry Unit Weight between 3.0 m and 5.0 m, and a downward increasing Dry Unit Weight below 10.0 m (below 8.0 m for borehole 15/82).

3.1.3. Particle-Size Analysis

The results of P. S. A. (see Appendices 1.1., 3.6., 2.2., and Fig. 12) reveal the marl to be a slightly sandy silty clay or clayey silt. Clay

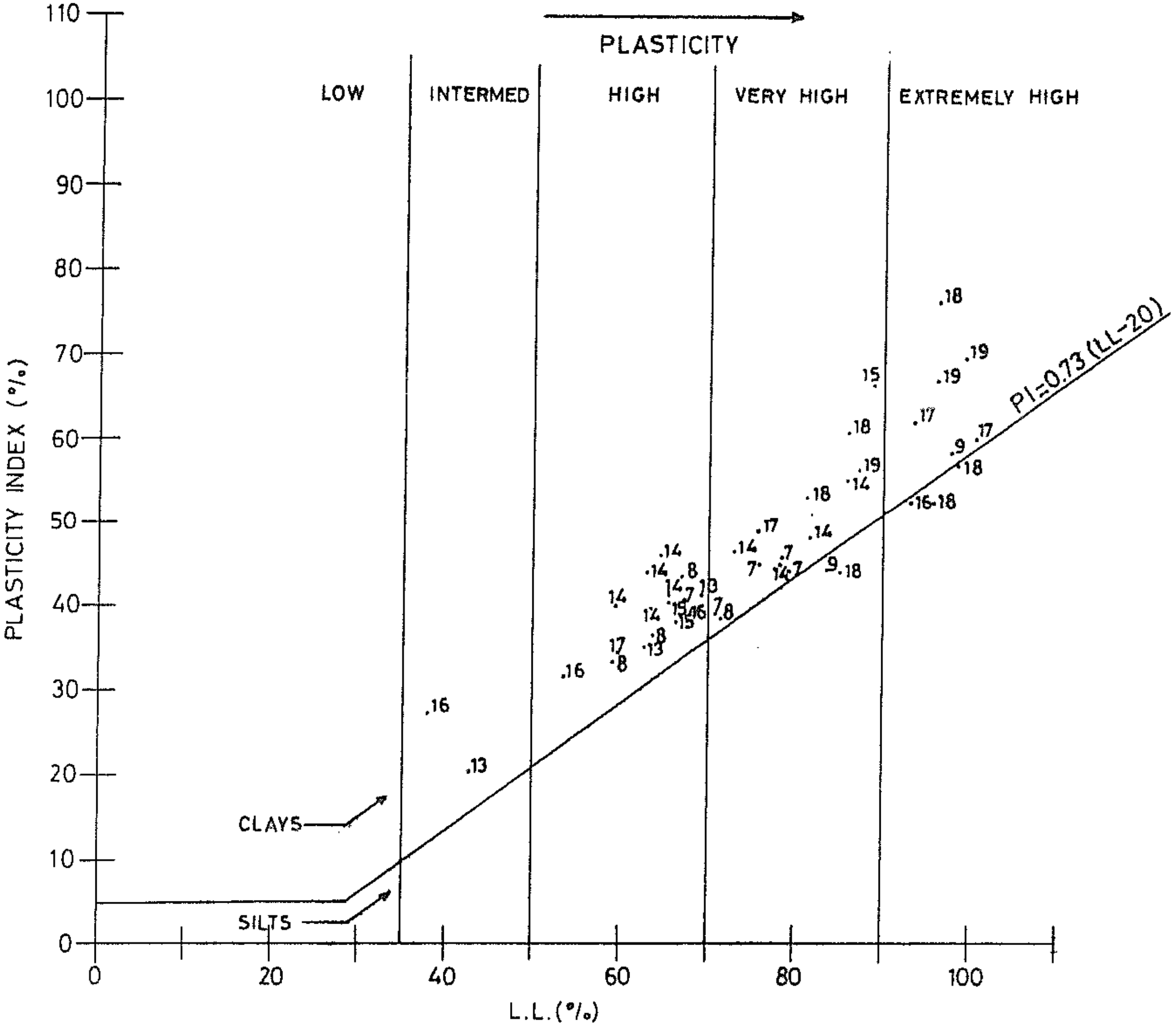


FIG.5

CASAGRANDE PLASTICITY CHART
BH's EG7/82 — EG19/83
(NUMBERS INDICATE BOREHOLE)

Fig. 5

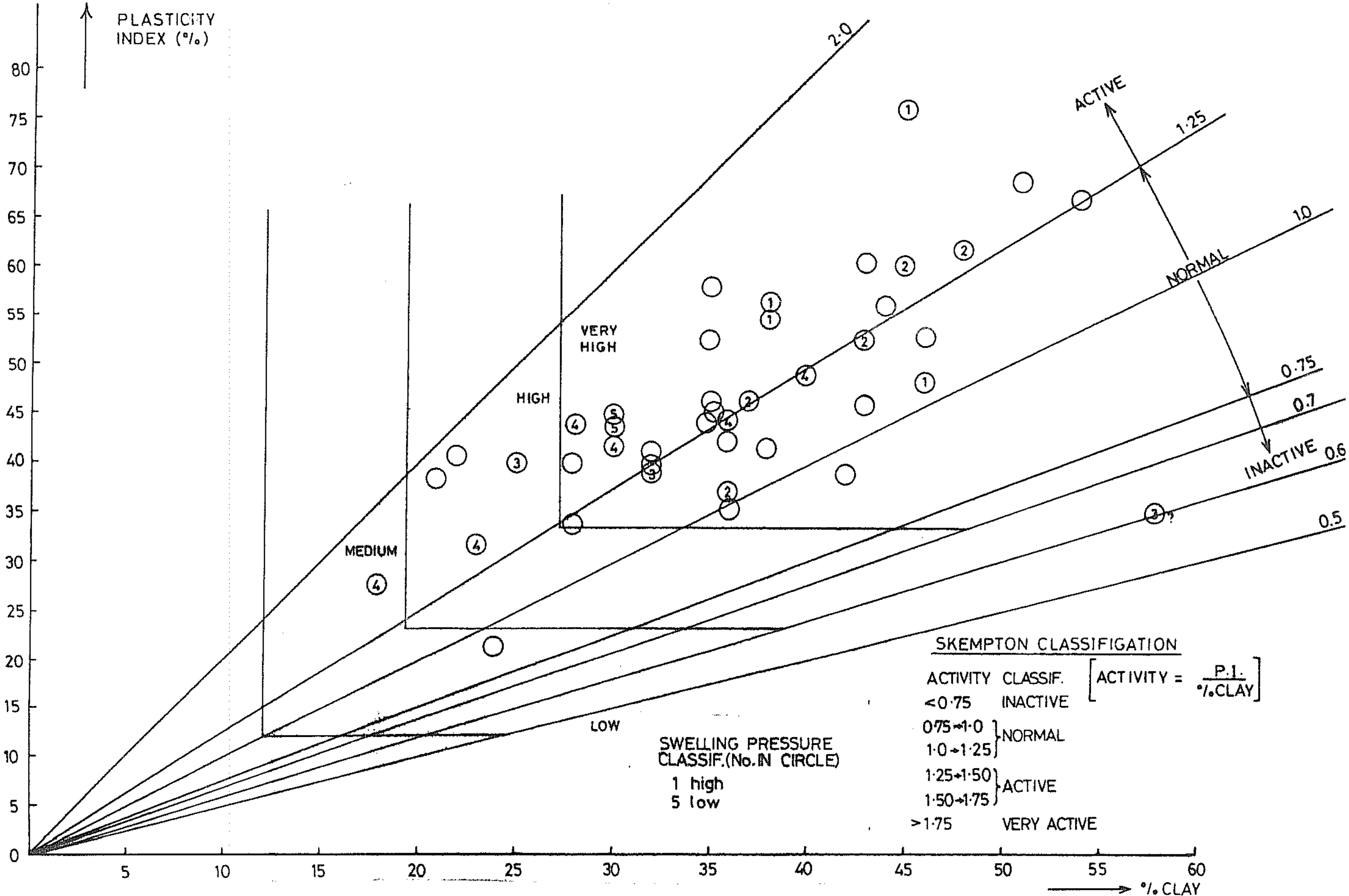
percentage ranges from 18% to 63% ($\bar{x}$ = 36.5, SD = 9.1, n = 44) and silt percentage from 31% to 69% ($\bar{x}$ = 54.4, SD = 7.0). The grading curves (see Appendix 2.2.) show that the marl is well-graded to moderately well-graded, frequently having similar proportions of fine, medium and coarse silt clay. Only one sample (marly calcarenite, EG 16, 5.0) exhibits gap-grading. There is a tendency for calcarenitic marls, marly calcarenites and other marls with high carbonate contents to be generally coarser than the ordinary marls; their modes lying in the coarse end of the silt range. The Folk triangular classification (see Fig. 12) of silt, sand and clay shows the marls clustered at the silty end of the area designated 'mud' and 'sandy mud'. Those samples which stray from the cluster are the sandy marls, calcarenitic marls and marly calcarenites.

A plot of % clay fraction v. Plasticity Index (see Fig. 6) givesthe 'Activity' of the marl's clay minerals. A considerable scatter of results is seen, ranging from normal to high Activity. A general lack of correlation between Activity and other plasticity-related parameters would suggest errors in the determination of the clay content. Aggregations of clay-sized particles may not have been broken down during sample preparation (Davis, 1967) leading to an underestimation of clay content and thus an overestimation of Activity. In the case of the Keuper Marl of the U.K. (not a 'true' marl) photomicrography has shown clay plate aggregates 'clothed' with quartz particles (Barden, 1972).

3.1.4. Moisture Content

The moisture contents measured immediately after core-recovery range from 14% to 38%; the variations being due to marl type, time of year, position relative to the water table, and drilling disturbance. Generally, moisture content increases from the surface to between four and six metres depth and remains relatively constant, or increases slightly below this to depths of 18 metres or more (see Appendix 1.1 and Fig. 7). The degree of saturation varies from 80% to 106% (values above 100% being clearly in error). Moisture contents generally lie close to the Plastic Limit. In elevated, well-drained areas (e.g. boreholes 9/82 and 13/82) moisture contents lie below thePlastic Limit (thus giving negative values for Liquidity Index), whereas in low-lying areas the moisture contents are at, or slightly above, the Plastic Limit.

Fig. 6



G.S.D.(E.Geol.)D.P.23/83

Fig. 6 ACTIVITY GRAPH FOR B.H.'s EG7/82 - EG18/82

3.2. Triaxial and S.P.T. Tests.

3.2.1. Triaxial Tests

A total of 20-Multi-stage undrained, unconsolidated (UU) Triaxial tests were carried out. Values of ϕu range from 5° to 26° ($\bar{x}$ = 13.2, SD = 5.5., n = 20) and values of Cu from 50 to 330 KPa ($\bar{x}$ = 149, SD = 70.3, n = 70.3). Undrained shear strength (Su) is plotted on the borehole logs (Appendix 1.1); this is calculated from the formula:- Su = Cu + Ptanϕu where P is the estimated present total overburden pressure. Stress-strain curves and Mohr Circles are given in Appendix 2.4.

For a 'standard' soil, structural strength is independent of cell pressure, i.e. a horizontal (ϕu = 0) Mohr-envelope is obtained for the 'total' stress condition and a unique Mohr Circle is obtained for the 'effective' stress condition. In this study, however, we find that strength is increasing with increasing normal stress (ϕu>0) in all cases. This may be due to two factors:-

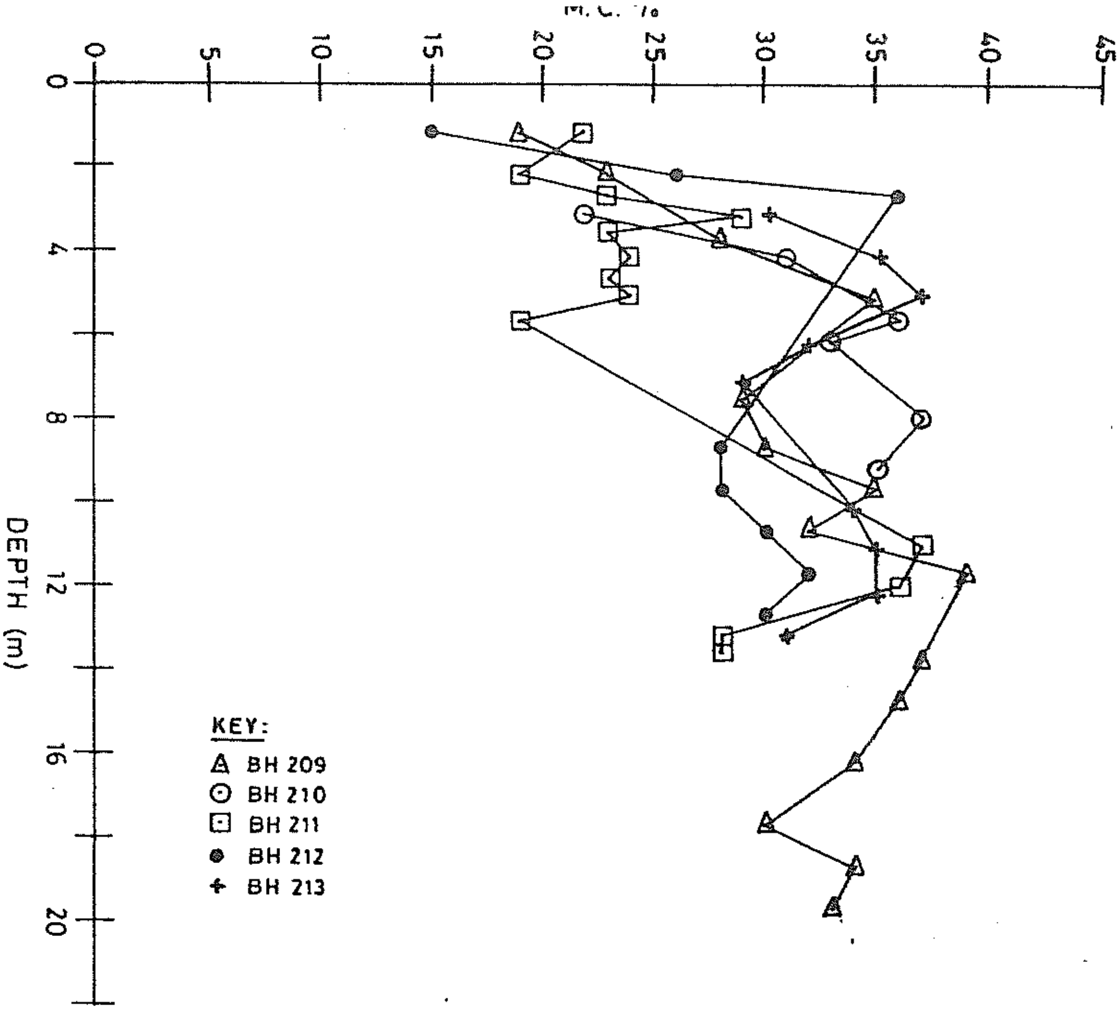
a) Partial saturation - as pressure increases air within the sample passes into solution resulting in a curved (concave downward) Mohr-envelope which levels off when the degree of saturation (S) approaches 100%.

b) Fissuring - below present overburden pressure, saturated fissured clays exhibit lower shear strength than the equivalent unfissured clay due to the closing-up of fissures during shearing. This may result in a curved Mohr-envelope similar to that for a partially-saturated sample.

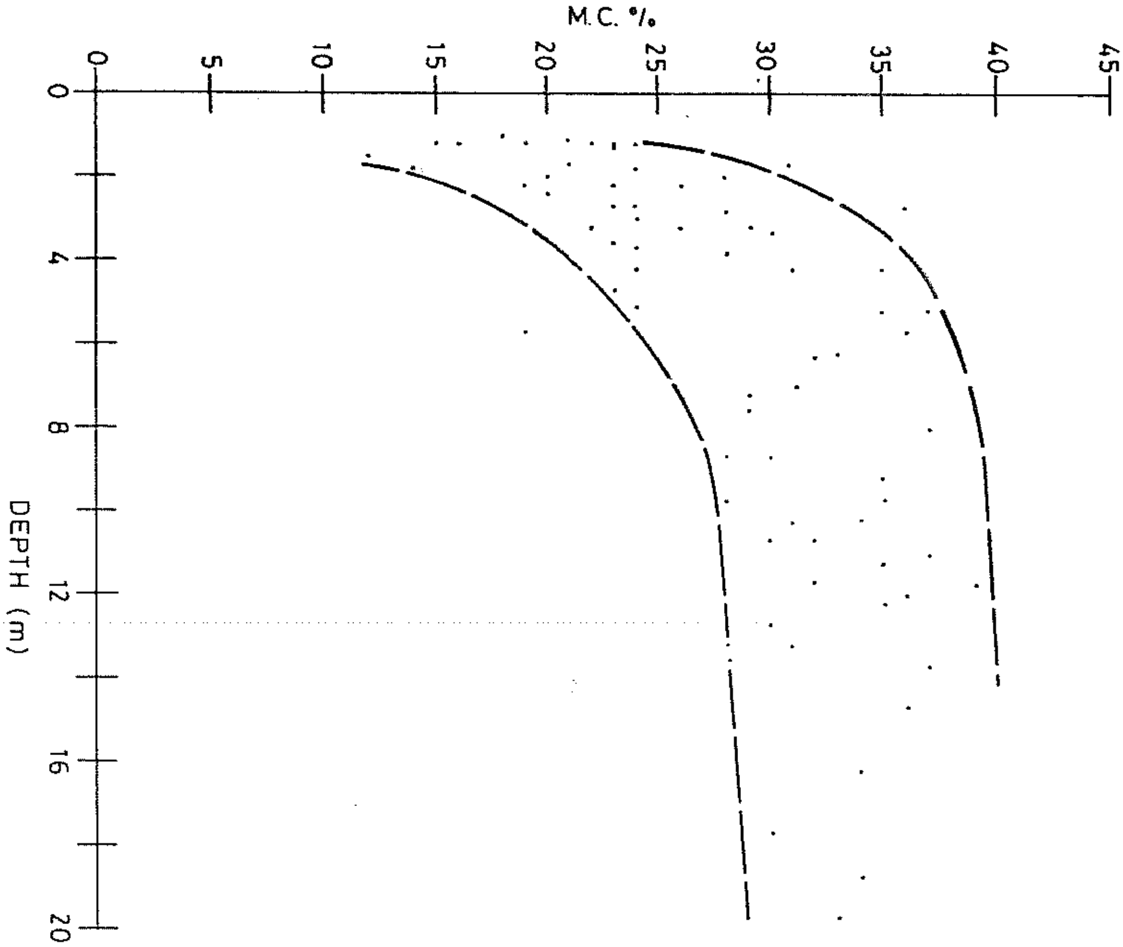
Both the above factors appear to influence the test results to some degree as ϕu>0 is obtained for unfissured marls and also for saturated marls. However, there is a moderately good inverse correlation (r = -0.8) between degree of saturation (S) and angle of friction (ϕu).

3.2.2. Standard Penetration Tests (S.P.T.)

Standard Penetration Tests were carried out at one metre intervals where possible; alternating with the U4 sampling. Thus no accurate



MOISTURE CONTENT / DEPTH PROFILE FOR BOREHOLE SAMPLES FROM THE MAKARIOS STADIUM SITE INVESTIGATION (ANON., 1972)



MOISTURE CONTENT / DEPTH PROFILE FOR ALL MARL SAMPLES FROM THE MAKARIOS STADIUM SITE INVESTIGATION (ANON., 1972) comparison can be made between S.P.T. and Triaxial results due to lithological variations from one metre to the next. However, depth trends of S.P.T. are comparable with those of Su (see App. 1.1.). Generally S.P.T. values are lower below, than above, the water table e.g. B.H. EG18/82). There is not clear correlation between S.P.T. or Triaxial strength and lithology. In some cases a decreasing fines content, and decreasing plasticity, is accompanied by a decrease in S.P.T. value (e.g. B.H's EG15/82 and EG16/82) and some highly-plastic marls exhibit high S.P.T. values (e.g. B.H.'s EG15/82 and Eg18/82. In fact, a positive trend between S. P. T. and Liquid Limit is indicated. Resistance to standard penetration of the marls may be summed up as high to very high (see also Anon, 1972). The S. P. T. value is, however, closely related to the moisture content and may be unreliable in cohesive soils.

3.2.3. Residual Strength

Triaxial results show a variety of undrainedstrengths from 'soft' to 'very stiff' or 'hard' (C. P. 2004, Table 2). Generally the strength of plastic marl in an undisturbed state is high. Equally, the drained residual strengths (see Fig. 8), though based on only three samples, are high, lying in the range ϕr = 20°-30°. The Residual shear angle decreases at low values of normal stress but much less so than is the case for the highly bentonitic Moni clays (see Fig. 8). At higher normal stress the residual shear angle decreases gradually and presumably levels off at some point; Lupini et al (1981) have identified three mechanisms of residual shear behaviour: 'turbulent', 'sliding' and 'transitional' (a combination of turbulent and sliding). The values of ϕr obtained depends on the relative proportions of platy and rounded particles. Turbulent behaviour results in ϕr values greater than 25° and sliding behaviour ϕr of between 5° and 20°. The sharp contrast in residual behaviour between the marls and the Moni clays (see Rep. No. EGARP KW/86/2), for example, is due to the high proportion of platy, low friction montmorillonite particles in the Moni clay and the dominantly silty high friction particles of the marl. In fact, the weakest of the three grey marls samples (7/82, 11.0) is more plastic than the other two (see Fig. 8). It is possible that, given more test data, a good positive correlation between Plasticity Index and residual shear angle may be found.

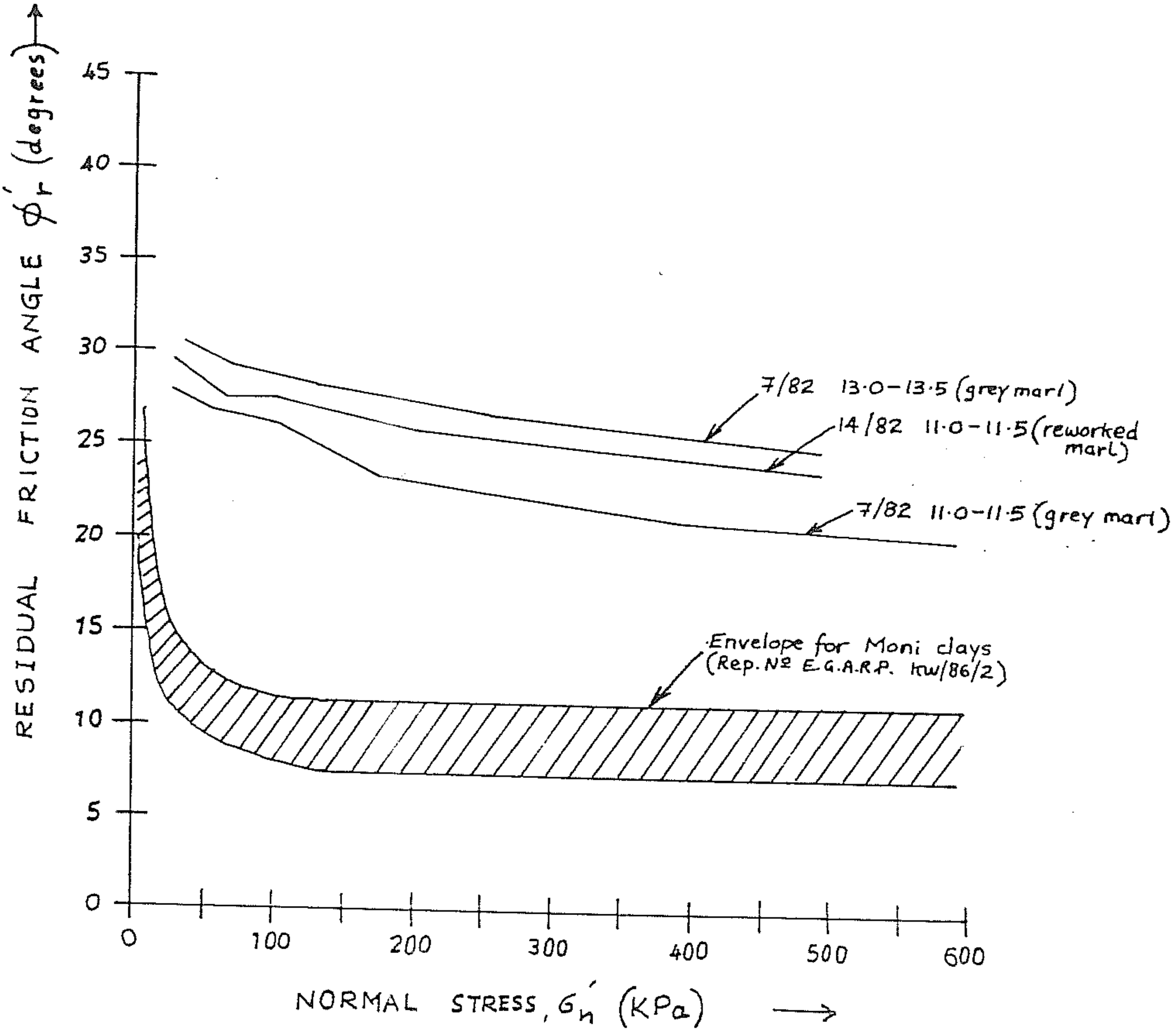


Fig. 8 RESULTS OF RING SHEAR TESTS

3.2.4. Deformation Moduli

The determination of deformation moduli in solids is subject to inaccuracies (Lambe & Whitman, 1979). The initial Young's tangent moduli, Ei, (given in App. 2.4) are affected by rate of loading, sample disturbance, sample size and other factors which affect the undrained strength. The influence of these factors on the modulus is considerably greater, however, than their influence on strength, particularly at the low stress end of the stress-strain curve. Generally triaxial tests on fissured clays give much lower values of Ei than either in-situ tests or back-analyses of settlements (Marsland, 1973). Also, the method of sampling has been found to be crucial; triaxial samples obtained from block samples may give moduli up to five times those from driven samples. Stress-relief after both drilling and extrusion in the laboratory may result in the formation of new fissures as well as the opening up of existing ones, thus resulting in a drop of modulus. Increasing the length of sample storage time also been found to reduce the modulus (Marsland, 1973).

In general, one may expect an increase of modulus with depth and a slight increase of modulus with decreasing triaxial sample size. Values of Ei obtained from large scale in-situ plate loading tests are between 2 and 5 times those obtained from conventional triaxial tests (Marsland, 1973). Variations within each class of marl are very great; for example, grey marl from borehole EG14/82 has an Ei of 28 MPa and similar marl from borehole EG7/82 has an Ei of 4.4 MPa. Similarly, the calcarenitic marls from boreholes EG15/82 and EG16/82 have Ei ranging from 7.5 Mpa to 30 Mpa. Values of Ei were plotted against O. C. R. but no correlation was found. Ladd (1964) puts forward a rather tenuous positive correlation between Ei and O. C. R. for heavily-overconsolidated clays. Values of Ei were also compared with the so-called 'equivalent modulus', 1/mv (i.e. the inverse of the modulus of volume change); Ei was found for all samples to be between one and three times the equivalent modulus.

3.2.5. Sensitivity, St

Defined as the ratio of undisturbed to remoulded strength (at the same moisture content), has not been specifically measured in this study.

However, the site investigation for the Makarios Olympic Stadium (Anon, 1972) shows clearly that the marls, in that area at least, are classified as normal to extrasensitive. Values of St range from 1.0 to 12.0 ($\bar{x}$ = 5.5, SD = 2.74, n = 27). A commonly used Sensitivity classification is: 1 → 2 slightly sensitive, 2 → 4 moderately sensitive, 4 → 8 very sensitive, 8 → 16 slightly 'quick'. The values of St are based on the results of unconfined, undrained compressive strength tests. All the samples having St>8.0 are weathered marls, but for St<8.0 there is no apparent distinction between weathered and fresh marls in terms of their sensitivity. The high sensitivity is to some extent reflected in the Low Dry Unit weight/strength ratio, but the values of St do seem rather high for a fissured, overconsolidated cohesive soil.

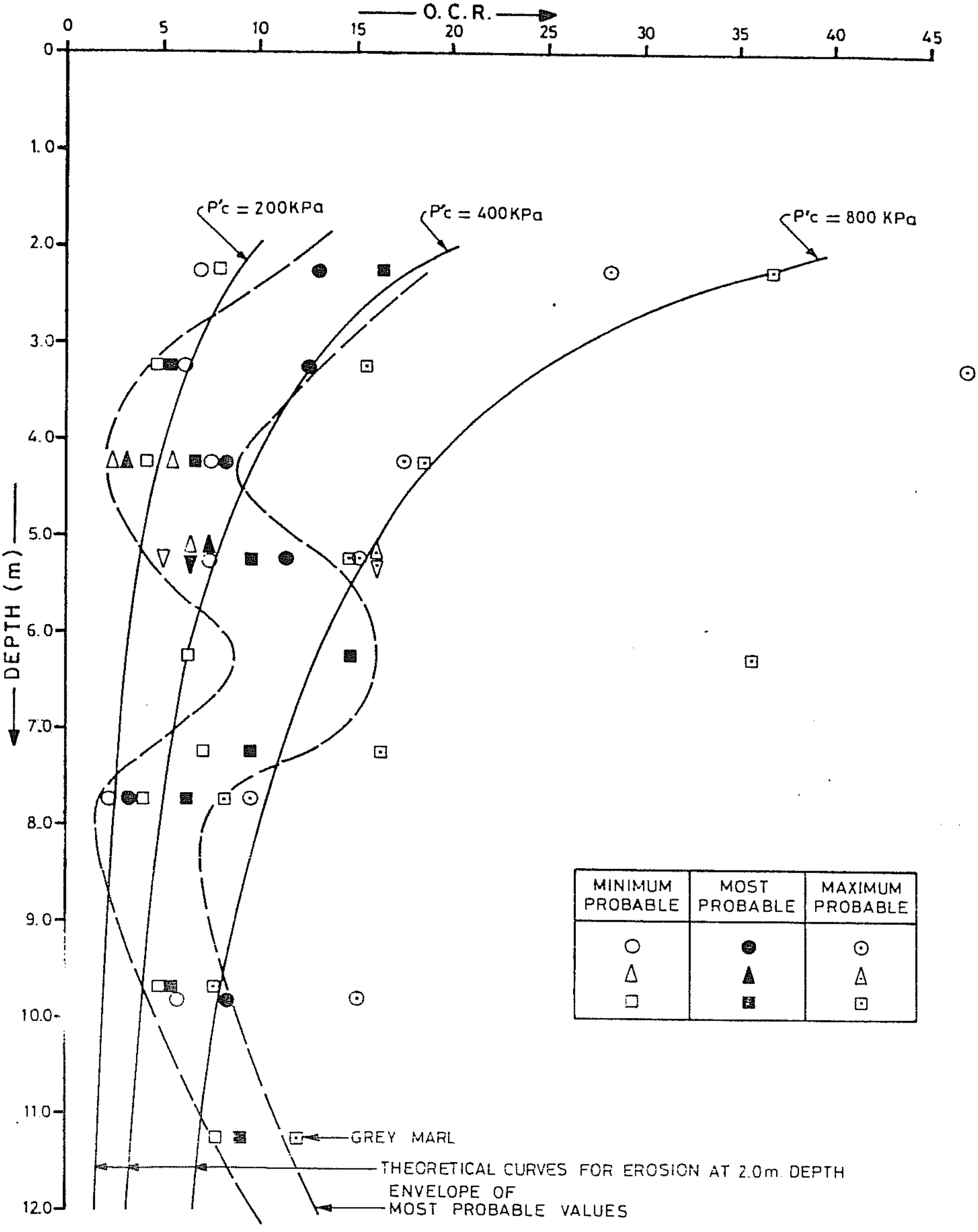
The phenomenon of sensitivity is associated with post-depositional build up of bonds due to cementation, leaching, overconsolidation. It should be noted that the maximum remoulded strength may be higher than the residual strength. However, as the Makarios Stadium data is from undrained tests, no direct comparison can be made with the results of the B. G. S. ring shear tests.

3.3. Consolidation Tests

3.3.1. Interpretation

A total of 25 tests were carried out; 17 by G. S. D. and 8 by B. G. S. (two of these were special high pressure tests). Three of the B. G. S. tests were duplicates of G. S. D. tests. The results are given in the form of e-logp´and m_v-logp´curves (Appendix 2.3) and the following derived parameters: Compression index Cc, swelling (or rebound) Index Cs, preconsolidation pressure (i.e. maximum previous overburden) Pc, the overconsolidation ratio O. C. R., modulus of volume change Mv and coefficient of consolidation Cv (see Appendix 1.4).

The present effective overburden pressure, Po´, has been calculated from the submerged unit weight (below the water table) and the bulk unit weight (above the water table) of the overburden as follows:-



G.S.D.(E.Geol.)172/83 Fig. 11 GRAPH OF OVERCONSOLIDATION RATIO (O.C.R.) v DEPTH

There is a poor correlation between O. C. R. and Cs and between O. C. R. and L. I. The divergence between minimum and maximum probable values appears to decrease with depth (see EG14/82), probably as a result of decreasing sample disturbance and weathering. O. C. R. is an important parameter which, unfortunately, is very difficult to measure with any accuracy using conventional test equipment.

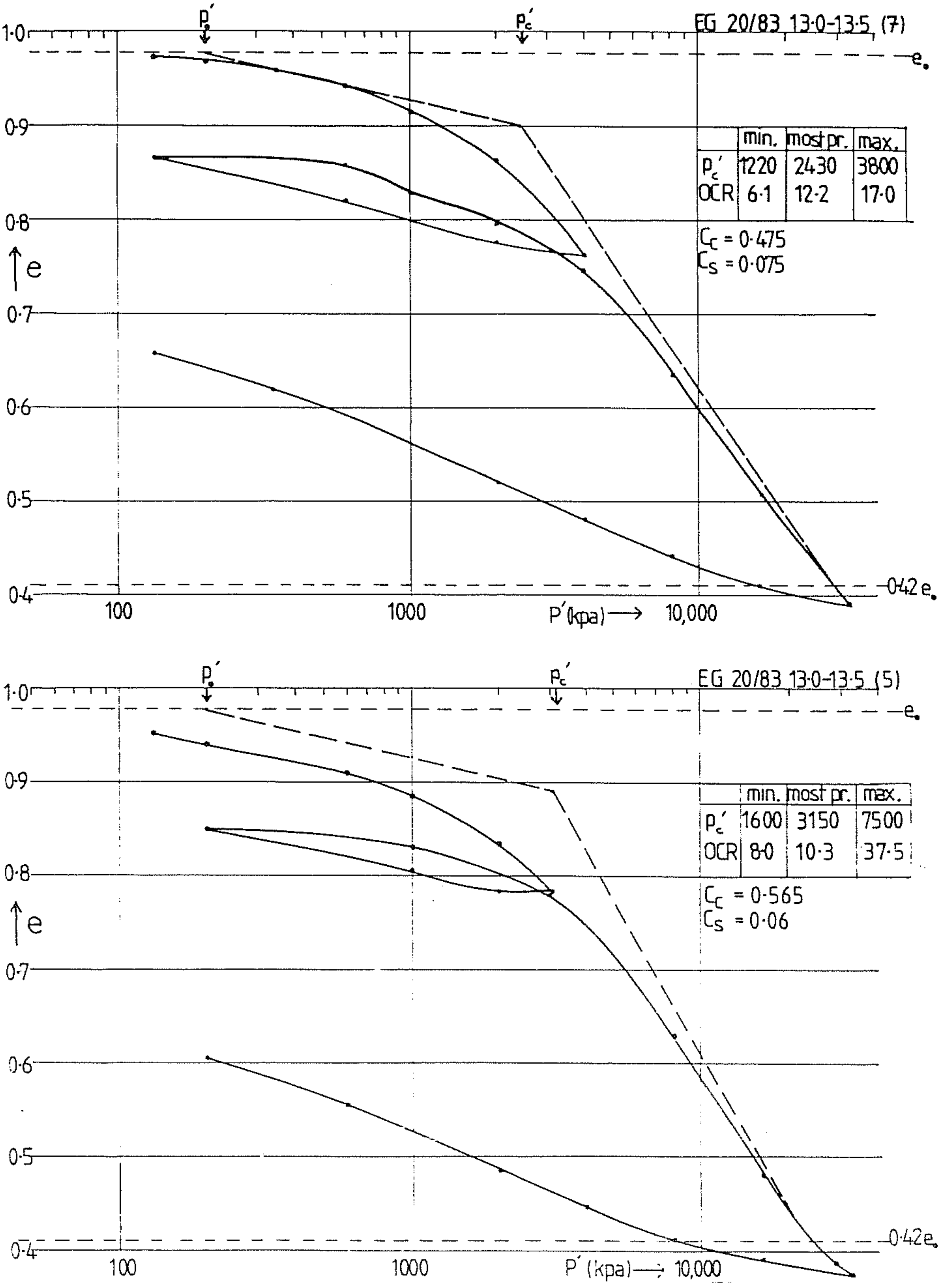
3.3.5. The Modulus of Volume Change, Mv($\propto \Delta e/\Delta p$) decreases with increasing pressure (see Appendix 2.3). Curves for each borehole tend to converge at high pressures (see Sridharan & Allam, 1982); (borehole EG14/82 is a good example) despite widely differing Mv values at low pressures (i.e. below 300 KPa). Sample EG14, 7.5 deviates from the general pattern by having a peak at 600 KPa; the reason for this is unclear. Samples EG16, 5.0 and 6.0, which are carbonate-rich marls, exhibit very large drops in Mv with increasing pressure.It has been suggested (Sridharan & Allam, 1982) that the convergence of Mv values with increasing pressure is due to the disruption of cementation/aggregation bonds leading to a similarity in the behaviour of those soils having basically the same constituents.

Curves of Cv against log pressure (not shown) are highly irregular and no pattern of behaviour could be evinced from them. This is entirely in keeping with previous experience in measuring Cv. It was noted, however, that samples EG17 3.0, 4.0 and 5.0 exhibited almost identical cv-logp curves and very little change in Cv between 100 and 1000 KPa pressure. Also, sample EG16, 6.0, a carbonate-rich marl, had a uniquely linear Cv-logp plot.

3.3.6. Permeability, K, calculated using the formula:- $k = m_v c_v \delta w$ is reasonably uniform throughout except for this lowest consolidation pressures where values of k are high. Permeability of the marls lies in the range $10^{-5} \rightarrow 10^{-4}$ cm/sec (i.e. $10^{-2} \rightarrow 10^{-5}$ darcys). No distinction in permeability appears to exist between the various types of marl between marls at different depths.

3.3.7. High-pressure Consolidation

Two special high-pressure consolidation tests have recently been carried out at E.G.A.R.P. using a Denison 15-ton testing machine adapted as



EG 20/83 13·0-13·5 (7)

	min.	most pr.	max.
p_c'	1220	2430	3800
OCR	6·1	12·2	17·0

$C_c = 0{\cdot}475$
$C_s = 0{\cdot}075$

EG 20/83 13·0-13·5 (5)

	min.	most pr.	max.
p_c'	1600	3150	7500
OCR	8·0	10·3	37·5

$C_c = 0{\cdot}565$
$C_s = 0{\cdot}06$

Fig. 12 <u>HIGH PRESSURE CONSOLIDATION TESTS</u>
<u>VOIDS RATIO (e) v Log PRESSURE (P')</u>

an oedometer to take standard 76 mm disc samples. Pressures of 32,000 KPa were attained during multi-cycle tests (see Perloff & Baron, 1976). The resulting e-logp´curves are given in Fig. 12. The suprisingly high values of Pc and O. C. R. obtained from these curves throws some doubt on the efficacy of the normal 'low pressure' consolidation tests. It is possible that the 'virgin' or normally-consolidated portion of the low-pressure e-logp´curves is never reached and that the values of Pc and O. C. R. are lower than they should be. However, the 'high pressure' tests are, to date, limited to two samples from 13.0 metres which may anyway have higher Pc and O. C. R. being at a greater depth than the 'low pressure' test samples. 'high pressure testing of shallow samples will hopefully resolve this question.

3.3.8. Secondary Consolidation

Values for the coefficient of secondary consolidation, c_α, range from 0.0002 to 0.0121. In general there is an increase in c_α, with each pressure increment. In some cases the c_α levels off at the 4th and 5th increment of load whereas elsewhere c_α is apparently still increasing at the highest increment. This supports the conclusion (section 3.3.7) that the virgin portion of the e-logp curve is not reached in many of the low pressure consolidation tests (Lambe & Whitman, 1979 p.413). However, graphs of c_α vs. logp (see Appendix 2.6) do in many cases show a distinct upturn at the point of maximum previous overburden Pc´, as might be anticipated.

3.4. Swelling Pressure Tests

3.4.1. Results

A total of 20 swelling pressure tests were carried out at B. G. S. using automatic apparatus, specially developed within E.G.A.R.P., which measures the pressure developed, on immersion in distilled water, of an 'undisturbed' oedometer-type sample for a 'zero' volume change condition (actual volume change ± 0.005 mm). The values of maximum swell pressure (Psw) range from 3.7 to 77.5 KPa; which may be considered to be low when compared with previous results, albeit using different methods, on marls (Katzir & David, 1969; Komornik & David, 1969; Erol & Dhowian, 1982).

3.4.2. Factors Influencing Swelling

The swelling pressure of a marl is dependant on the following factors:-

a) Cementation i.e. that proportion of carbonates and other salts contributing to cementation will tend to reduce swelling pressures (Sridharan & Allam, 1982; Hardy, 1965).

Yong and Warkentin (1975) found that the presence of iron salts markedly reduced swelling (but see Warkentin & Bozozuk, 1961).

b) Aggregation of clay-size particles into 'crumbs' affect the mobilization of full swelling potential as well as other mechanical properties depending on grain-size and surface area.

c) Initial moisture content and dry density determine what percentage of the swelling potential is actually mobilized. Also seasonal desiccation can result in cementation and aggregation.

d) Remoulding or disturbance of marl can have a strong influence on swelling pressure due to the breakdown of cementation, preferred particle orientation (disrupted by disturbance) and removal of any effects of stress-history (e.g. overconsolidation). Remoulding tends to reduce swelling pressure (Warkentin & Bozozuk, 1961; Yong & Warkentin, 1975).

e) Stress-history: overconsolidation in the laboratory has been shown (Mesri et al, 1978) to increase the rebound of consolidated samples. Also it is likely that overconsolidation in the field will result in preferential orientation and closer packing of clay platelets (Horseman et al, 1983; Komornik & David, 1969) resulting in increased welling pressures. This is not borne out by the test results however, where a negative trend is suggested between swelling pressure and O. C. R. (but see (d) above).

f) Clay Mineralogy: The type and amount of clay mineral present, as well as the pore-water salt concentration, will have an important effect on the swelling behaviour (Yong & Warkentin, 1975). Pure montmorillonites, and in particular sodium montmorillonites, will produce large swelling pressures (Pusch, 1980; Grey et al, 1980), due to their very large specific Surface Areas. The presence of calcium montmorillonite in the marls tested, ranging from 8% to 29% (see section 4.3), does result in higher swelling pressures although the correlation is poor (see Fig. 13); the contribution of the other factors, listed above, is probably the reason for this.

g) Macrostructure: The presence of discontinuities, whether open or filled, probably affects the swelling behaviour in as much as pore-fluid transmission and differential swelling will influence the rate and, possibly, the amount of swelling pressure. Open fissures will tend to dissipate swelling pressures which cannot thus be recorded. This behaviour may be representative of field conditions. The material infilling many fissures, a light-grey plastic clay, is likely to have different swelling properties from the bulk brown marl. This veining can be clearly seen in the photographic log (see Appendix 1.1) and is discussed in section 5.1.

3.4.3. Correlations with Swelling Pressure

Swelling pressures have not been found to correlate well with Dry Density, Activity or Plasticity Index as might be expected (Komornik & David, 1969; Seed et al, 1962; Holtz & Gibbs, 1954). However, Hardy (1965) found poor correlations between swell and Atterberg Limits and Activity, which he attributed to alteration of structure in the tests. A negative linear correlation is suggested by Erol & Dhowian (1982) between swelling pressure and liquidity index (log) for active Saudi Arabian clays. A poor correlation (r = -0.43) is found for the marls, however, (see Fig, 14). A slightly better positive correlation is found between swelling pressure and swell index. Cs, obtained from the consolidation test (see Fig. 13). Attempts at multi-regression analysis to relate swelling pressure to more than one index parameter have proved unsuccessful. Komornik & David (1980)

Fig. 13a MONTMORILLONITE DETERMINED BY IGS V SWELLING PRESSURE (I.G.S.)

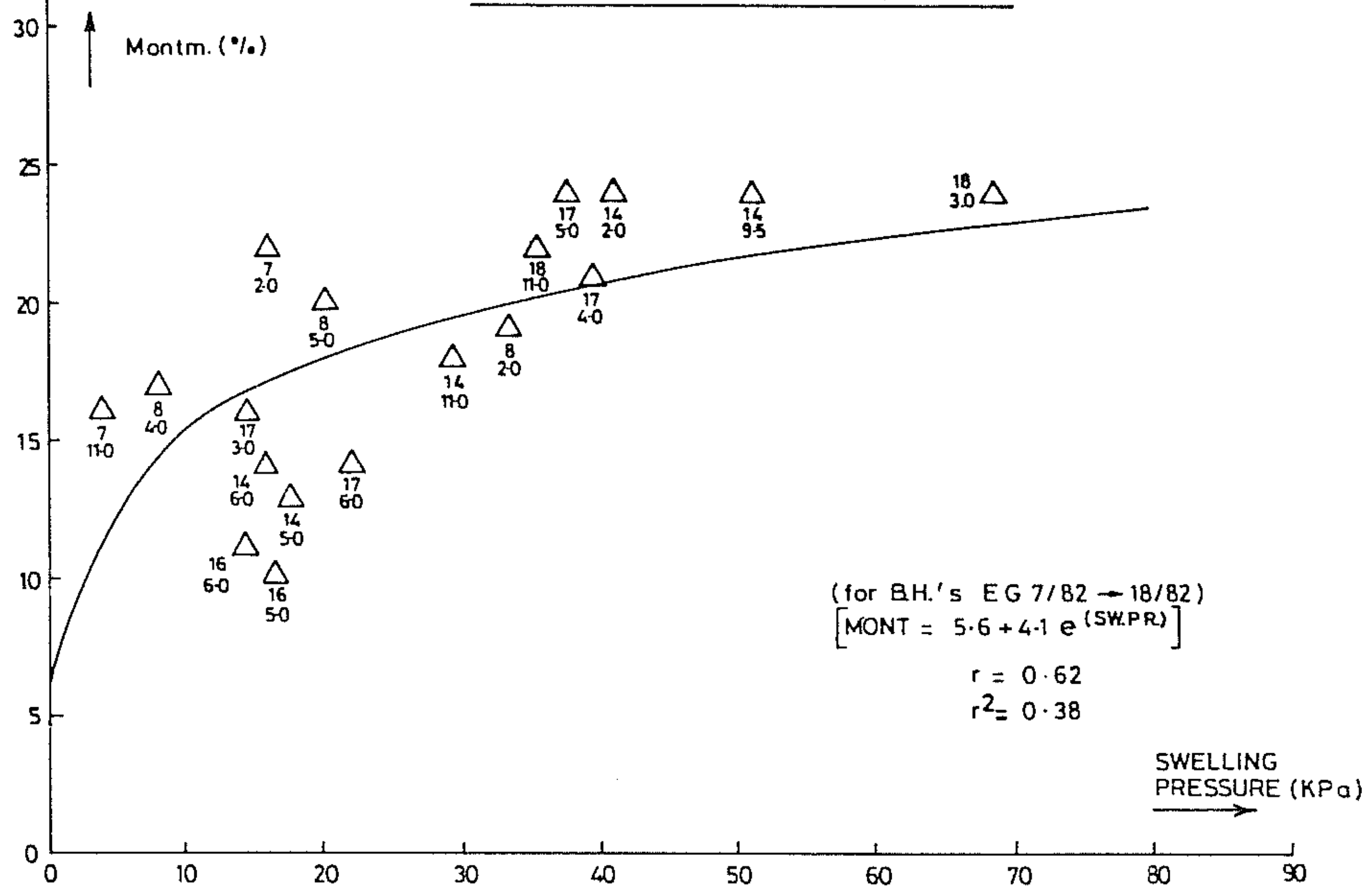
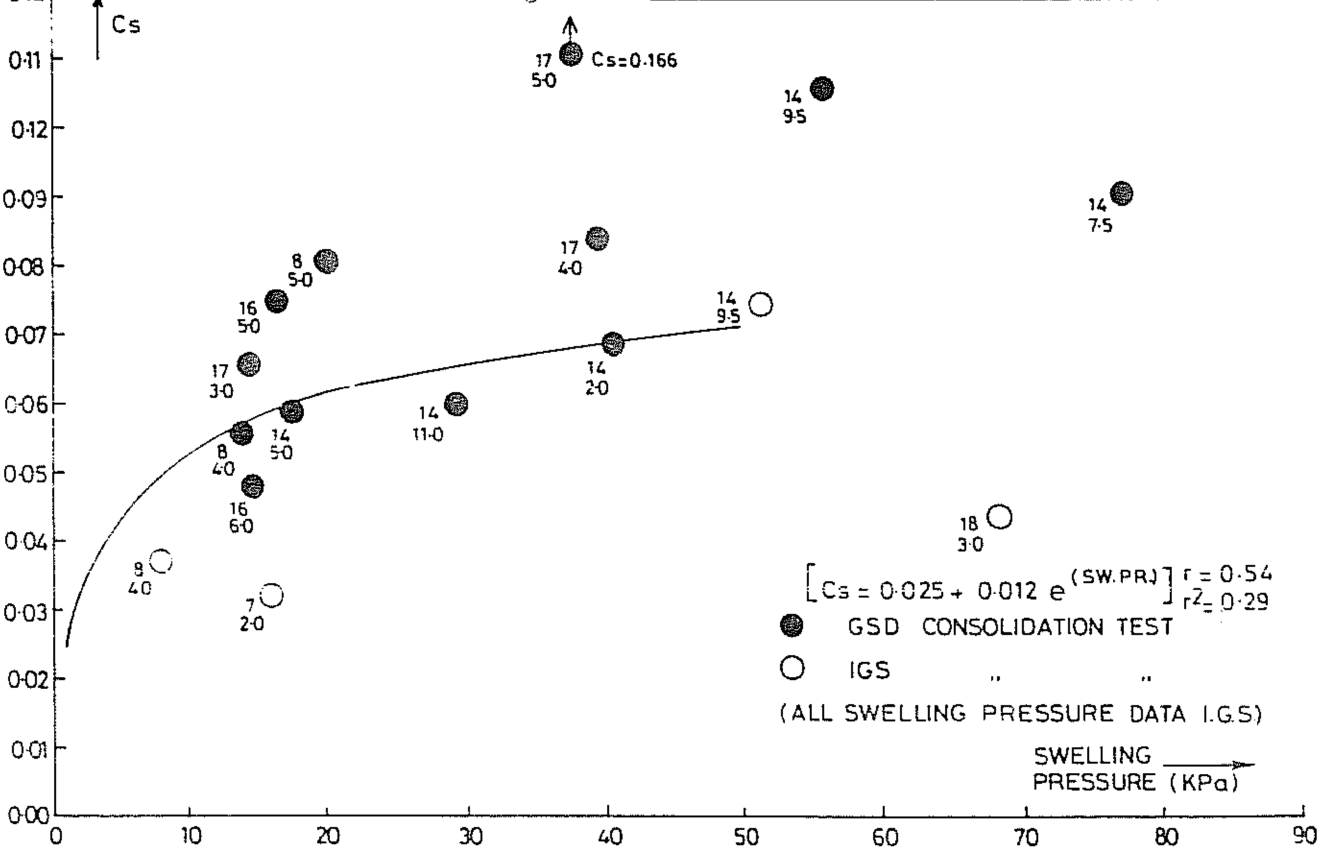


Fig. 13b SWELLING INDEX V SWELLING PRESSURE



have apparently achieved such a relationship for Israeli marls using the following formula:-

$$\log P = 0.0208\ (LL) + 0.665\ (\gamma_d) - 0.0269\ (M/C) - 1.868$$

Applying this formula to the Nicosia Marls resulted in a coefficient of correlation r = 0.56 between measured and calculated swelling pressure.

3.4.4. The Mechanisms of Swelling are complex and not fully understood, (Hobbs et al 1983). The development of a swelling pressure at constant volume, and equally the unrestrained swelling, on wetting of a sample is due to three factors:

a) Elastic rebound on removal of stress; the proportion of this factor actually measured in the laboratory is probably small. It is more significant at lower moisture contents.

b) Hydration (or crystalline swelling) is the adsorption of monomolecular layers of water on planar surfaces of the clay crystal lattice. This becomes significant in swelling at low moisture contents. Hydration can occur at very high confining pressures.

c) Osmotic swelling is due to a high concentration of ions held by electrostatic forces in the vicinity of clay surfaces. This "structured" water layer may persist up to 100% from the surface of a clay platelet. In the case of montmorillonite-rich clays, which have high surface areas, osmotic swelling becomes a major factor. This is particularly true where preferential orientation of clay platelets occurs (due, for example, to overconsolidation). The swelling process follows a logarithmic curve with time (see Appendix 2.5) and reaches a maximum when the repulsive forces balance either the attractive physico-chemical forces (in the case of unrestrained swelling) or the reaction of the applied load in the case of the swelling pressure test.

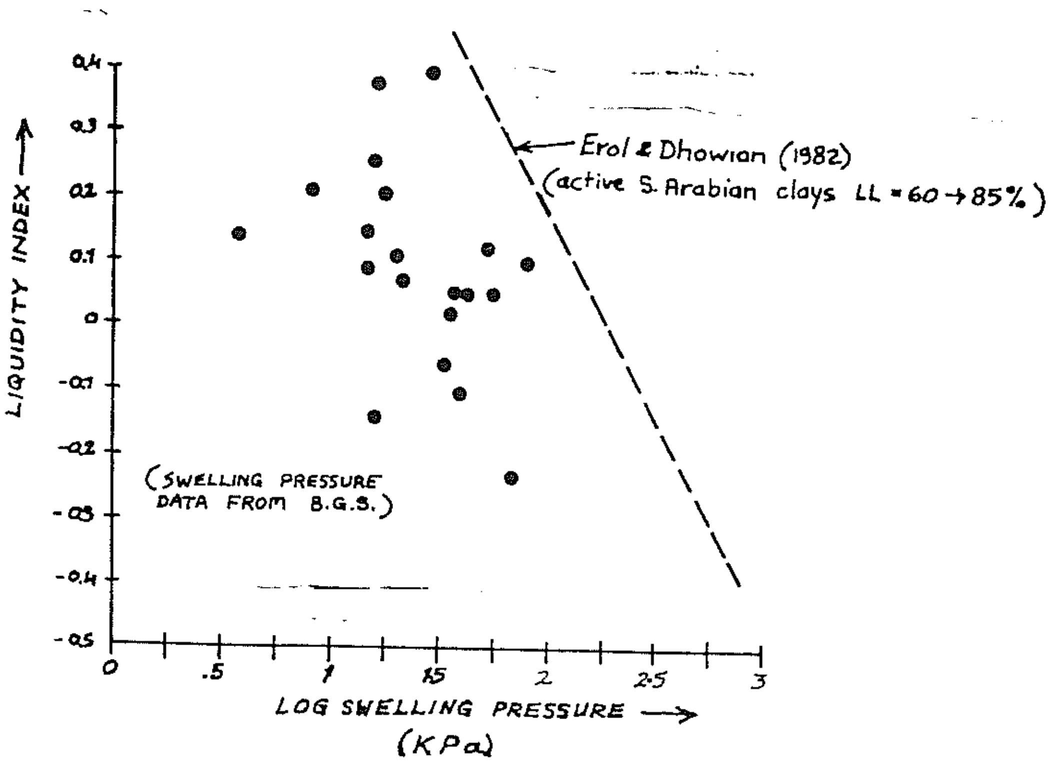


Fig. 14a GRAPH OF LIQUIDITY INDEX v Log SWELLING PRESSURE FOR B.H.'s EG7/82 - EG18/82

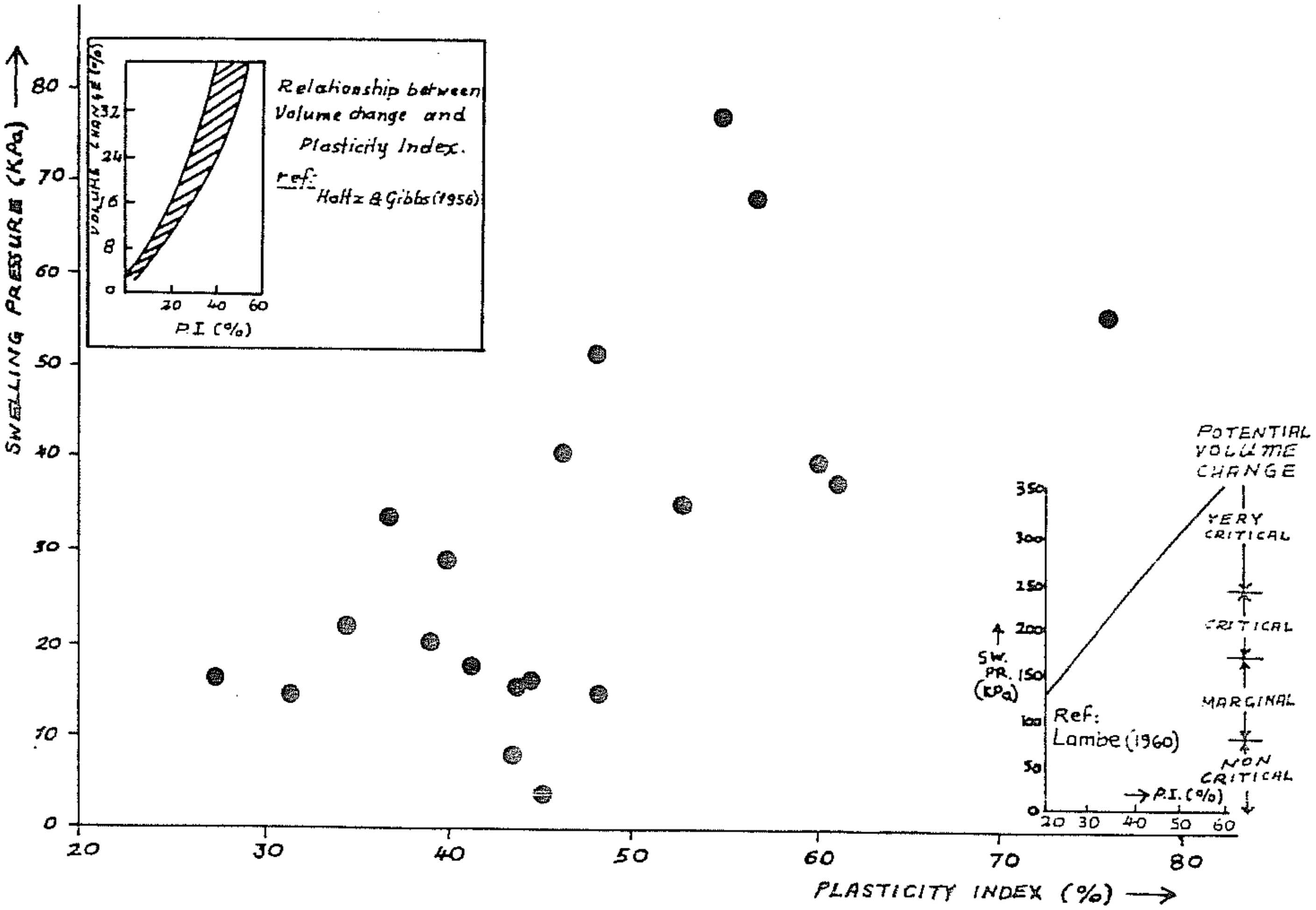


Fig. 14b GRAPH OF SWELLING PRESSURE v PLASTICITY INDEX FOR B.H.'s EG7/82 - EG18/82

Fig. 14

3.4.5. Interpretation

The direct measurement of small swelling pressures is dependent on the full pressure being transmitted to the boundaries of the sample. In fact, joints and pockets of coarse or loose material may 'absorb' some part of the total pressure developed. This would be particularly applicable to laminated, sandy and fissured marls.

A logarithmic increase in swelling pressure with decreasing moisture content is clearly demonstrated in Fig. 15. This behaviour is due largely to osmotic swelling at the moisture contents used, which are well above the shrinkage limit. During periods of drying, shrinkage occurs as the result of a decrease in the osmotic repulsion forces and consequently a moving together of the clay platelets caused by the now dominant Van Der Waals and Coulomb forces of attraction, (see Horseman et al 1982). An increase in moisture content, due either to saturation or ingress of water vapour, causes a reversal of this process resulting in swelling.

The build-up of swelling pressure with time is shown in Appendix 2.5. Maximum pressure is generally reached between half an hour and one hour, with the exception of samples from borehole EG 18/82, which peak at between 2 and 5 hours. After five hours no samples showed genuine increases in swell pressure. Higher peak swelling pressures do not necessarily imply longer swelling times (e.g. boreholes EG 14/82). Times to reach peak pressure are suprisingly low when compared with other cohesive soils (Yong & Warkentin, 1975) which may take days or even weeks. There is a moderately good positive correlation between swelling pressure and plasticity Index (r = 0.66). The swelling pressures are nevertheless low when compared with those for soils of similar plasticity. Comparisons with the literature are difficult, however, due to differences in the testing technique. The complexity of the factors affecting swelling, listed in section 3.4.2, make a regional assessment of swelling behaviour difficult. Clearly, some samples have a higher potential for swelling than others, irrespective of the moisture content, but these seem to occur as thin horizons, usually of high plasticity within lower-swelling deposits, as can be see from the wide variations within

Fig. 15 GRAPH OF Log SWELLING PRESSURE (Sw.PR.) v MOISTURE CONTENT (M/C)

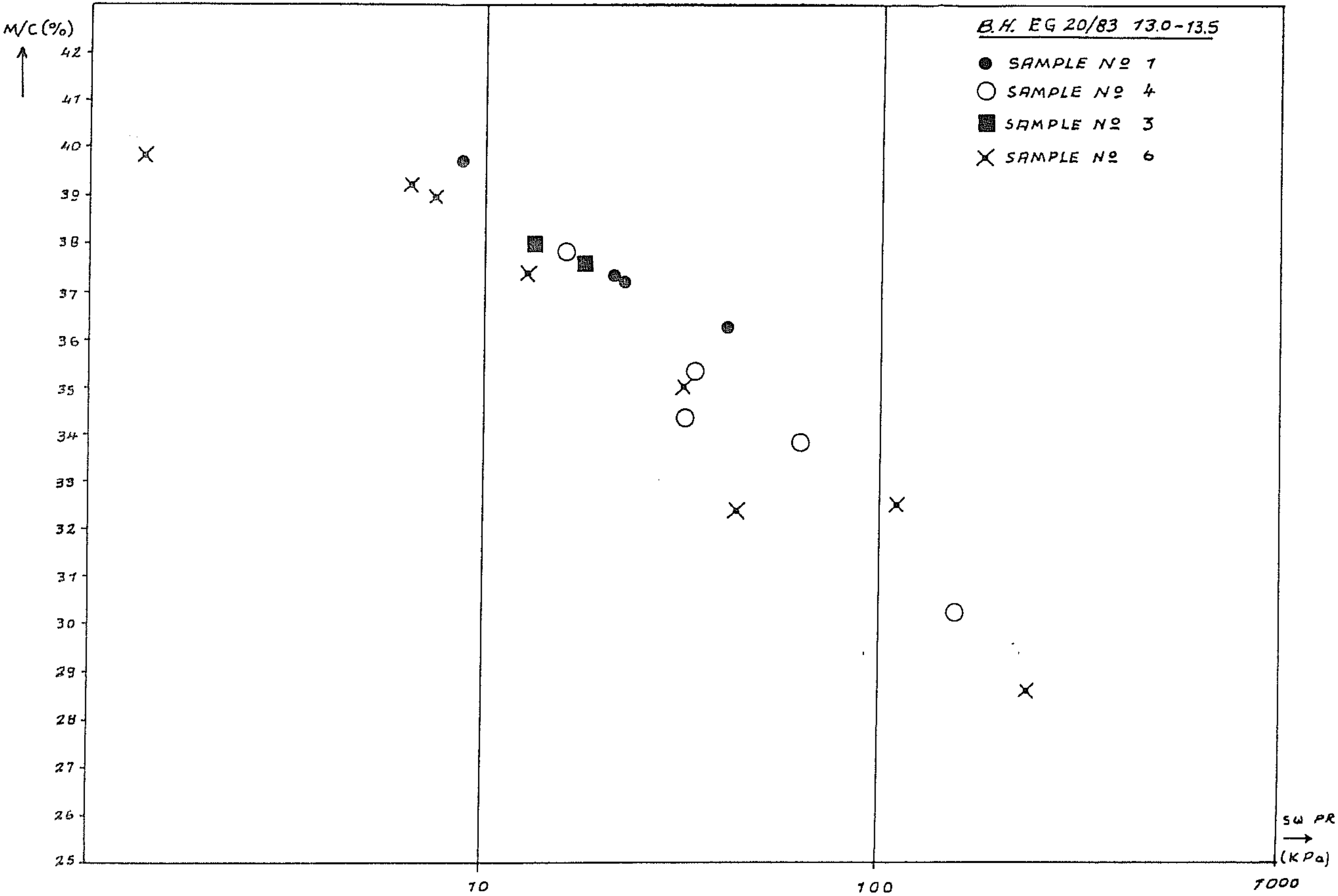


Fig. 15

each borehole. The notion that some areas of Nicosia are "high-swelling" and others not is an over-simplification which is not borne out by the results. All the samples with swelling pressures in excess of 35 KPa occur in boreholes, EG 14/82 (Lykavitos), EG 17/82 (Ayios Nicolaos) and EG 18/82 (Ayia Varvara). Unfortunately, samples from boreholes EG 15/82 (Productivity Centre), reputedly an area of "high-swelling" were unsuitable for testing.

Samples from the western part of the study i.e. "Apalos" marls (boreholes EG 7/82, EG 8/82 and EG 13/82) generally exhibit low swelling pressures (i.e. 35 KPa).

The E.G.A.R.P. swelling pressure test is in its prototype stage of development and thus is subject to certain problems, in particular electrical "drift" as shown by the "apparent" increase in swelling pressure of sample EG 7/82, 11.0 beyond 4 hours duration. More significant than the equipment problems, however, are those due to sample disturbance (in particular disturbance which allows swelling to take place prior to the test), moisture content changes during transport, storage, and testing (which affects both pore fluid viscosity, hence permeability; and also electrical drift characteristics). The test does succeed in measuring the true swelling pressure developed by the sample. To what extent this reflects the true swelling pressure of the in-situ material is, as yet, unclear, due to a total absence of field swelling data.

4. MINERALOGICAL AND CHEMICAL TEST RESULTS

4.1. X-Ray Diffractometry

The tests carried out at B. G. S. are described in section 2.2.6. The results are shown in Appendix 1.2. They reveal a uniformity of mineral content with only minor variations. Calcite, Calcium montmorillonite and quartz are present throughout, with small quantities of feldspar, dolomite and mica present only in some samples. Gypsum was found in only two samples, both of which have high carbonate contents (EG 16, 6.0 and EG 17, 6.0).

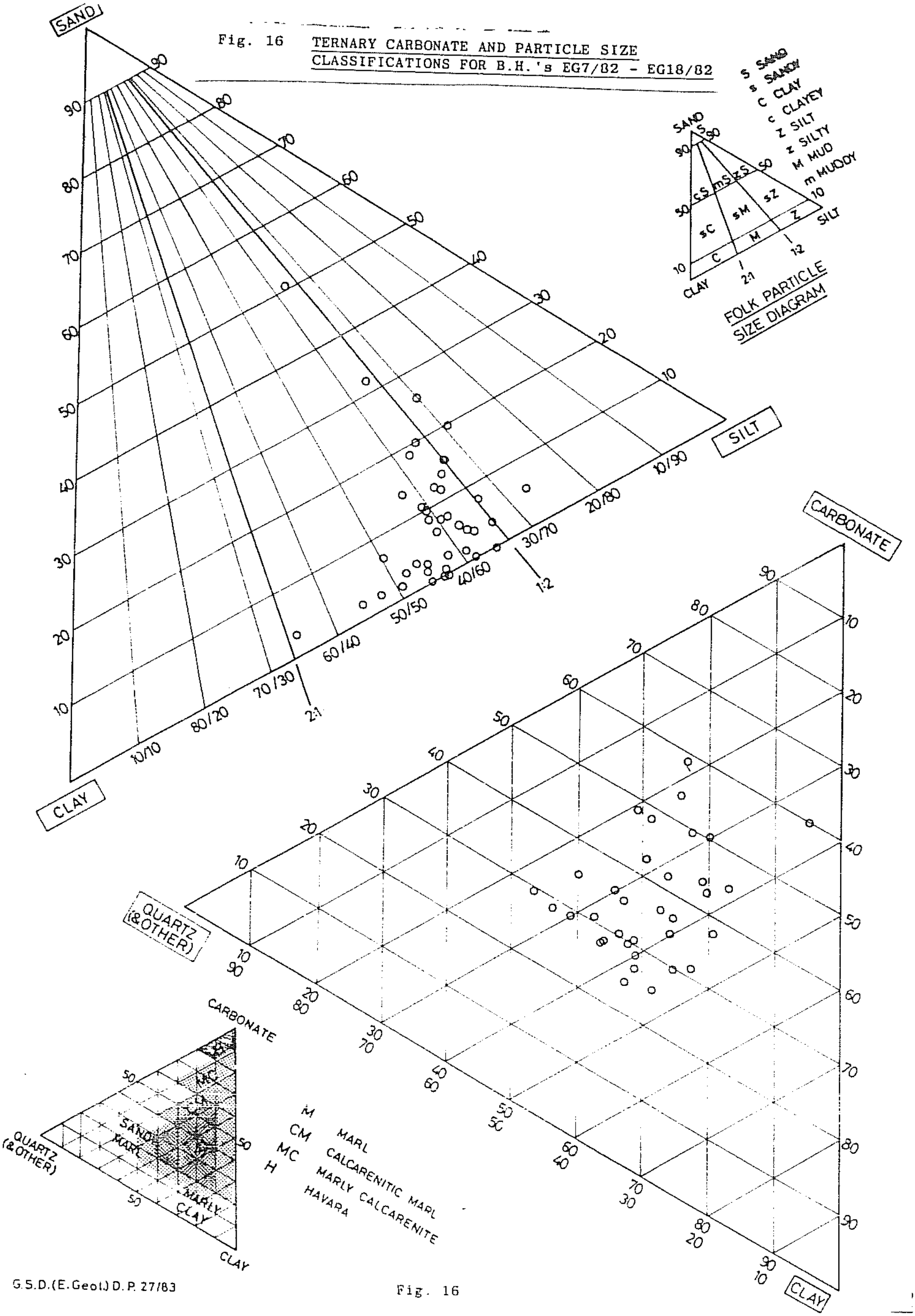
There are no overall trends with depth or location as far as these results are concerned. Total carbonate content (B. G. S.) ranges from 20% to 58%. Calcium-montmorillonite content (B. G. S.) ranges from 10% to 31%. The three grey marl samples (EG 7 11.0 and 13.0 and EG 14, 11.0) do not differ mineralogically from the brown marls (but see Section 4.2.). Samples described as "marly calcarenites" or "calcarenitic marls" do, in most cases, have high carbonate contents (>50%). Samples with either high carbonate or high montmorillonite contents are not confined to any particular area of the Nicosia marl outcrop.

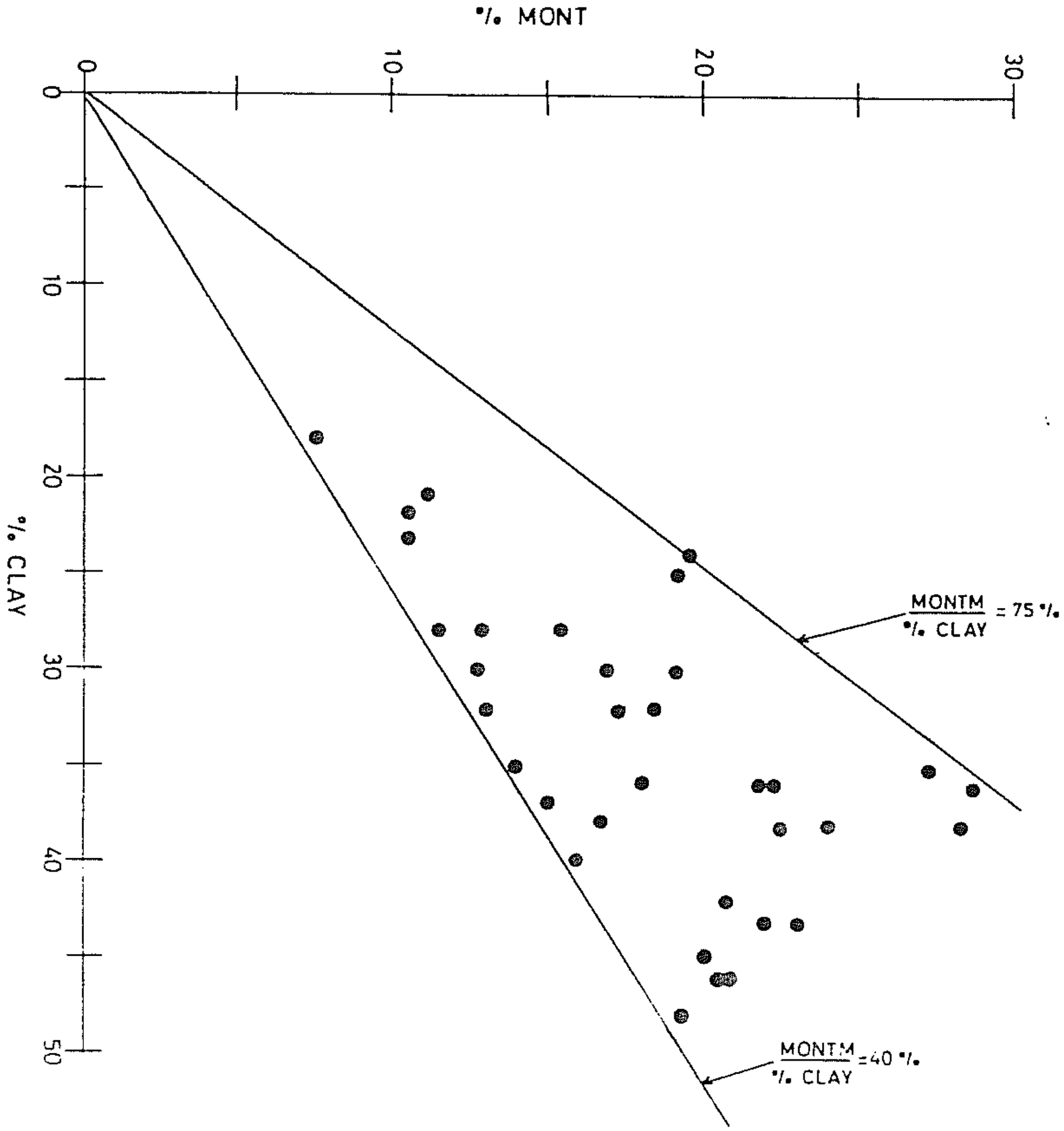
A ternary diagram of carbonate/clay/quartz (and others) is shown in Fig. 16. This shows that the marls are grouped centrally with the exception of EG 9, 3.0. There is, however, a problem in that not all the clay fraction (<0.002 mm) comprises clay minerals as can be seen from the plot of montmorillonite content v % clay fraction (Fig. 17). All samples have between 40% and 75% of their total fraction as montmorillonite.

The remainder of the clay-size fraction must be taken up by carbonate and other minerals. The generally high values of Activity (see Fig. 6), however, suggest low contents of inactive components such as carbonate in the clay fraction.

Dolomite is a product of the metasomatic action of magnesium-bearing waters on calcium carbonate. A high feldspar content would indicate a proximity to the parent rock. Only sample EG 7, 2.0 has a high feldspar content.

Fig. 16 TERNARY CARBONATE AND PARTICLE SIZE CLASSIFICATIONS FOR B.H.'s EG7/82 - EG18/82





MONTMORILLONITE CONTENT (G.S.D.) v CLAY FRACTION

BH's EG 7/82 → EG18/82

Fig. 17

4.2. Chemical Tests

Chemical analyses for carbonate, sulphate and montmorillonite content are given as depth profiles for each borehole in Appendix 2.1. There are some discrepancies between the montmorillonite and carbonate contents obtained by B. G. S. from x-ray diffractometry and by G. S. D. from chemical tests, ($r = 0.85$ for B. G. S. - G. S. D. carbonate correlation and $r = 0.85$ for B. G. S. - G. S. D. montmorillonite contents) due to the difference in test method.

Two types of sulphate test were carried out:

a) acid soluble,

b) water soluble.

Sulphate contents lie below 0.6% with the exceptions of EG 7/82 below 6.0 m, EG 14/82 below 10.0 m and EG 16/92 above 5.0m (see Appendix 2.1). The three samples of "grey" marl (EG 14, 11.0; EG 7, 11,0) and EG 7, 13.0) have significantly higher total sulphate contents (2.74%, 2.07% and 2.68% respectively) than the "brown" marls, whilst their water soluble sulphate contents remain low ($<0.3\%$). Also the X-Ray analysis has not detected any gypsum in the "grey" marls. Thus it would appear that the high sulphate content in the "grey" marl is not due to a soluble sulphate such as calcium or magnesium (gypsum) but rather to a non-sulphate transition-metal sulphate such as iron sulphate. C.P. 2004 (1972) states that for total sulphate $>0.5\%$ and soluble sulphate $>0.25\%$ some form of sulphate resisting cement will be required in all cases.

It is not clear whether the high sulphate content is characteristic of the "grey" marl or simply due to the proximity to the weathering, and water-movement horizon of the "grey"/"brown" marl contact.

4.3. Montmorillonite

Montmorillonite is the high-alumina end member of the smectite group of expanding clay-lattice minerals, carrying both silica and alumina in solution. In acid solution ($pH \simeq 4$) the solubilities of silica and alumina are such that relatively much alumina and relatively little silica are present, thus favouring the formation of kaolinitic material (Al_2O_3: SiO_2 =

1:2); in alkaline solutions (pH=8-9) much more silica is present thus promoting the formation of montmorillonite (Al_2O_3: SiO_2 = 1:4); calcite is deposited at pH 7.8. Generally calcium favours the formation of smectite and in marls, calcium must be removed before there is an alteration of primary silicates; carbon retards the disintegration of primary silicates. Smectites are produced from the prolonged weathering of alumina-silicates (particularly calcic feldspars) in a reducing environment or one of low rainfall (Montmorillonite has an Si:Al ratio of 2:1). Smectites are derived from basic or ultra-basic igneous rocks containing considerable proportions of magnesium. Calcium montmorillonite may be produced by base exchanges from sodium montmorillonite or directly from a parent rock containing calcic plagioclase such as anorthite, or ferromagnesian minerals. Desert soils and zonal aridic soils (rainfall $<$ 0.65 m/yr.) may contain smectite and illite as well as attapulgite, palygorskite and sepiolite (found in S. African and Israeli marls). Feldspars weather readily to smectite whereas quartz remains unaltered by weathering or transport. Smectite itself alters to mica with time and is seldom found in deposits earlier than Mesozoic. Montmorillonite alters to illite and chlorite by potassium and magnesium fixation respectively, particularly in a marine environment and also with increasing depth of burial. Smectite is less evident below 1,000 metres and very unusual below 3,000 metres.

Ducloz (1964) describes the marl of the Nicosia Formation as "massive or poorly-stratified and composed of very angular grains of pyroxene, plagioclase, calcite and magnetite.....it represents the ultimate comminution of debris eroded from the igneous rocks of the Troodos Massif".

4.4. Carbonate

Calcium and to a much lesser extent magnesium carbonate form a significant proprtion of almost all deposits in the Nicosia area including the marls. Carbonate contents of the marl range from 20% to 58%. The carbonate rich marls include the so-called "marly-calcarenites" and "calcarenitic marls" found in boreholes 7, 15 and 16. The degree of cementation of a marl is not necessarily indicated by the carbonate content. Induration can occur concurrently with deposition and marls of identical composition may occur in both cemented and uncemented form within short lateral and vertical distances (see Fookes & Higginbottom, 1975). The ability of any one geotechnical parameter to identify cementation is limited. The relatively high values of sensitivity (see section 3.2.5.) however, point to a loss of strength with disturbance which may result from a breakdown of cementation. Leaching (i.e. movement of soil-water by capillary and surface evaporation) is clearly responsible for the formation of the "kafkalla" duricrust and "havara" secondary carbonate found at, or near to, the ground surface, (Everard, 1963). However, the role of leaching specifically, or post-depositional water movement in general, in the distribution of carbonate within the marl is unclear. Dry density is generally fairly low, but this is not related specifically to the carbonate content. Carbonate-rich marls contain less water (r = 0.71 for m/c v CARB) and less clay minerals (r = 0.73 for MONT v CARB). No correlation is found between carbonate content and plasticity index which suggests that a proportion of the carbonate is of silt and clay size and having no plastic properties thus "dilutes" the Activity of the marl. In fact, a weak positive correlation (r = 0. 51) is found between carbonate content and Activity, a fact which is not readily explained.

5. WEATHERING AND STRUCTURE

5.1. Weathering

The Nicosia marls may be divided into the "grey" marl and the overlying "brown" marl. The thickness of the brown marl ranges from about 5m to 20m in the Greater Nicosia area. Little information is available on the geotechnical or chemical nature of the grey marl due to the fact that site investigation boreholes do not usually reach these depths. Indications to date are that the grey marl has been primarily weathered from the surface to form the brown marl and that the brown marl has subsequently undergone leaching, deformation and secondary weathering. The colour change from grey to brown is a result of oxidation of iron compounds ($Fe^{2+} \rightarrow Fe^{3+}$ +e) in particular iron oxide. Microfracturing of the brown marl has followed this weathering process, and subsequently secondary alteration has spread from the fissures as a result of water movement. The process may be summarized as follows:

a) Oxidation weathering. This penetrates to some depth partly depending on the drainage patterns, topography, climate, etc..

b) Erosion and stress relief. These probably occur simultaneously and in stages. The stress relief results in fissuring of the overconsolidated marl allowing ingress of water.

c) Secondary weathering. Movement of aggressive groundwater through the fissure system leads to alteration of the brown marl adjacent to the fissures. Transport of fine-grained material into open fissures or drying cracks may also occur in marls close to the surface.

Examination of core from boreholes EG 19/83 and EG 20/83 (see Appendix 1.1) has revealed two kinds of secondary weathering:-

a) Fissures, some of which show slickensiding and small shear displacement of the order of 0.1 → 1.0 cm., in "veins" of light grey plastic clay. Two phases of alteration are sometimes seen in which a darker grey clay is surrounded by an earlier lighter-coloured clay (e.g. EG20/83, 5.5-6.0). The light grey clay in the "veins" or formation from the overlying Athalassa or Kakkaristra formations. South of Nicosia the surface separating the two formations is uneven and displays a low relief suggesting that the period of erosion which took place before the deposition of the overlying Athalassa formation was not of long duration.

1.3. Athalassa Formation

The first good description of the formation was given by Henson et al (1949). The formation is described as a series of low-lying fossiliferous, current-bedded sandstones, detrital limestones and stratified silty marls overlying the Nicosia or older formations in the Mesaoria snd coastal areas. Liondari Hill, a conspicuous flat-topped mesa, southeast of the Government Stock Farm at Athalassa is taken as type locality. In this locality, there is some 45 metres of Athalassa sediments resting with an angular unconformity over the marls and calcarenites of the upper part of the Nicosia Formation. The Athalassa Formation is a distinct unit (Ducloz, 1964) even in the centre of deposition but its facies vary considerably southwest and west of the type area. The marine Athalassa Formation, characterised by its buff, fossiliferous beds grades laterally into an heterogeneous sequence of terrestrial, lacustrine, brackish and marine strata which were mapped previously in part, as marine Fanglomerates and, in part, as marine Pliocene marls (GASS 1960; BEAR, 1960). This mixed continental, brackish and marine deposit is named the Kakkaristra Formation.

The Athalassa Formation, in the type area consists of several beds of medium-to coarse-grained, fossiliferous, current-bedded calcarenite interbedded with sandy, fossiliferous marls. The calcarenites are very similar to the calcarenites of the Nicosia Formation, although in general they are coarser grained. In places they contain lenticles of conglomerates made up of poorly rounded pebbles derived from the calcarenites of the Nicosia Formation and of well rounded pebbles of igneous rocks of the Troodos Massif. In some specimens of the Athalassa calcarenite the proportion of detrital parts is higher than in the typical Nicosia calcarenite.

Ripple-marks were observed occasionally on stratification planes of the Athalassa calcarenites. Their predominant alignment is about N70E but in one place it swings towards the north with a strike of N30E.

The proportion of calcarenites to marls varies from place to place. In the type area the calcarenites and marls are evenly represented but southward, in the Yeri area and southeast of Laxia the calcarenites predominate over the marls and in places, form almost the bulk of the formation.

The Athalassa Formation is horizontal or is tilted with gentle dips which rarely exceed 3°. The formation is much less jointed than the underlying Nicosia Formation and the principal joint sets trend NNW and NNE.

The contact between the Athalassa Formation and underlying Nicosia Formation is an angular uncomformity with a difference of dip between 5 to 10 degrees. However, in a few places, near Laxia for instance, both formations are flat-lying but the contact, is disconformable. In the area directly south and west of Nicosia the Athalassa Formation transgresses deeply over a truncated sequence of the Nicosia Formation.

In the type-locality, the Athalassa Formation is overlain unconformably by the Kantara Gravel, a younger Pleistocene unit, but westward near Strovolos and Engomi it is overlain conformably by the freshwater brown silty marls and clays of the Apalos Formation.

The thickness of the Athalassa Formation ranges from 6 metres directly south and west of Nicosia, to about 45 metres in the type area and southeast of Laxia.

The Athalassa Formation is very fossiliferous but there are still some uncertainties about its age. REED (1930, 1935) did not recognize the formation as a separate stratigraphical unit; but collected macrofossils which from his descriptions, come from the Athalassa Formation. At the type locality of the Athalassa Formation fossils from the middle part of the formation are definitely attributed by REED to the Astian whereas fossils collected in the upper part of the formation are considered as possible Calabrian. South of the type locality, on the Eylenja-Yeri road, a rich macrofauna from beds near the base of the Athalassa Formation is again reported to the Astian. Fossils, also found in the lower part of the formation, are attributed to the Astian or possibly to the Calabrian. The only unquestionable Calabrian fauna reported by REED from the Athalassa Formation, in the Mesaoria, comes from a small conical hill near Pyroi.

Thus the Athalassa Formation according to REED's findings is Pliocene (Astian) and extends in the Calabrian. HENSON et al. (1949) give a short list of fossils from the Athalassa Formation a Calabrian age but this is given with a question mark. Bones of mammals found in the Kakkaristra Formation, a freshwater-brackish equivalent of the Athalassa Formation, will confirm that the age of the Athalassa Formation is definitely younger than the Pliocene and very likely Calabrian.

1.4. Apalos Formation

The Apalos Formation (Ducloz, 1964) is a series of near-horizontal siltstones, conglomerates, greywackes and marls of freshwater origin conformably overlying the Kakkaristra or the Athalassa Formations. It is overlain unconformably by a thin veneer of coarse gravel, the Kantara Gravel. The formation is, as a whole, well stratified and obviously has been deposited in an aqueous or subaqueous environment. Except for reworked foraminifera the formation is notably barren of fossils. It is well exposed at Kantara Hill and west of Kato and Pano Lakatamia. It had been previously mapped as Marine Fanglomerates (Bear, Gass, 1960).

The dominant and most characteristic sediment of the Formation is a brown to yellowish grey clayey to marly to poorly stratified siltstone. It is frequently mottled with different hues of brown and grey. The brown colouration increases noticeably in intensity in the upper part of the formation where even some reddish brown colours are noted. The siltstones are intercalated toward the base of the formation with beds of grey silty marl, and locally with thin beds of greywackes; whereas in the upper part of the formation there are several intercalations of stratified gravel and poorly consolidated conglomerate. These rudaceous beds increase progressively in number, thickness and coarseness towards the top of the succession.

1.5. Younger Superficial Deposits

Overlying the Nicosia, Athalassa and Apalos Formations there is a succession of generally thin igneous gravels which cover large tracts of the study area. These are seen capping the mesas and frequently occur as a cemented duricrust, (Chapman, 1974). The surface gravels weather to form a thin residual soil. The Kantara gravel is found capping the hills of the Apalos formation to the North West and notably to the East and South East of Strovolos. The Kambia gravels cover a large area of over-lying ground from Strovolos to Xeri. The Laxia gravel is found in a broad band immediately West of the Kambia gravel deposit and also to the West and South East of Laxia where is overlies the Kakkaristra and Athalassa formations. Kambia and Laxia gravels are found infilling channels eroded in the Kantara gravel.

The Xeri Alluvium occupies the Pedieos river notably at Dheftera, Strovolos, and to the North East of Nicosia town. Other alluvial deposits are of more recent origin and form the lower terraces.

The ancient walled town of Nicosia stands in the Pedieos valley at the point where the river broadens and veers Eastward. To the South the distinctive E-W scarp of the Nicosia formation calcarenite rises sharply from the marl plain and is particularly prominent at Eylenjia (see Fig. 3). This calcarenite has provided the bulk of Nicosia's building stone, as evidenced by numerous quarries.

2. SAMPLING AND TEST METHODS

2.1. Sampling Methods

A total of 11 boreholes were sited to sample the main marl outcrops in in Nicosia and the greater Nicosia area (see Fig. 1). A list ofthe types and quantity of tests carried out is given in Fig. 4. A total of 44 samples were taken for testing. Boreholes were drilled using the G. S. D.'s Mobile 838 power auger and samples were recovered by pushing a U4 (0.1 x 0.45 m) sample tube into the case of the augered hole. In most cases the U4 was filled by applying continuous hydraulic pressure. In a few cases hammering was required. In the intervals between U4 sampling, SPT's using a split-spoon head were carried out. The holes were drilled to depths of between 6 m and 13.5 m with the exceptions of EG 19/83 and EG 20/83 which were deeper. On completion, each borehole was fitted with a PVC standpipe piezometer set in a 1 m gravel pack and sealed with bentonite. The nine holes drilled during May and June, 1982 (i.e. boreholes EG 7/82 → EG 18/82) have had water-levels monitored by G. S. D. staff at monthly intervals (see Appendix 3.1.

Moisture-content sub-samples were taken on site and U4 samples sealed with hot paraffin-wax and grease and despatched to the G. S. D.'s soils laboratory for testing. In the laboratory samples were extruded from the U4's using a power-driven machine and sub-samples for Triaxial, consolidation and Index testing removed and trimmed as required. Sub-samples were also taken for despatch to B. G. S. Keyworth; these were wrapped in aluminium foil and then coated in wax. Additional moisture content determinations were made after extrusion of the core.

2.2. Testing Methods

2.2.1. Triaxial Tests

The Triaxial tests carried out at the G. S. D. were of the Multi-stage (3 stage) unconsolidated, undrained type (UU) without pore-pressure measurement. Samples, nominally 100 mm x 200 mm, were tested on Wykeham-Farrance cell using a compressed air system. Results, taken from Mohr-circle plots, are given as ϕu and Cu or as estimated shear strength

FIG.4

RECORD OF LABORATORY TESTS

BOREHOLE NO.	DEPTH (m)	MOISTURE CONTENT	DENSITY	SPECIFIC GRAVITY	ATTERBERG LIMITS	PARTICLE SIZE	FREE SWELL	CONSTANT VOL. SWELL	CHEMICAL TESTS				X-RAY DIFF. (BGS)		TRIAXIAL (UU Test)	CONSOLIDATION
									Carbonate		Sulphate	Montmorillonite	Surface Area (Mont.)	Others		
									GSD	BGS						
EG 7/82	2.0-2.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	4.0-4.5	0			0	0	0		0		0	0	0	0		
	6.0-6.5	0			0	0			0		0	0			0	
	11.0-11.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	13.0-13.5	0	0	0	0	0	0		0		0	0	0	0	0	0
EG 8/82	2.0-2.5	0	0		0	0	0	0	0	0	0	0	0	0		
	3.0-3.5	0	0		0	0	0		0		0	0				
	4.0-4.5	0	0	0	0	0		0		0			0	0		0
	5.0-5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EG 9/82	2.0-2.5	0			0	0	0		0		0	0				
	3.5-4.0	0			0	0	0		0	0	0	0	0	0		
EG 13/82	2.0-2.5	0			0	0	0		0		0	0				
	3.0-3.5	0			0	0	0		0		0	0				
	4.0-4.5	0			0	0	0		0		0	0				
EG 14/82	2.0-2.5	0	0	0	0	0	0	0	0	0	0	0	0	0		0
	3.0-3.5	0	0	0	0	0	0		0		0	0			0	0
	4.0-4.5	0	0	0	0	0	0		0		0	0			0	
	5.0-5.5	0	0	0	0	0	0	0	0		0	0				
	6.0-6.5	0	0		0		0	0	0	0	0	0	0	0	0	
	7.5-8.0	0	0	0	0	0	0	0	0		0	0				0
	9.5-10.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11.0-11.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
EG 15/82	3.0-3.5	0			0	0	0		0		0	0	0	0		
	7.5-8.0	0	0	0	0	0	0		0		0	0	0	0		0
	9.5-10.0	0	0	0	0	0	0		0		0	0	0	0	0	0
EG 16/82	2.0-2.5	0			0	0	0		0		0	0	0	0		
	4.0-4.5	0							0		0	0	0	0	0	
	5.0-5.5	0							0		0	0	0	0	0	
	6.0-6.5	0							0		0	0	0	0	0	0
EG 17/82	3.0-3.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	4.0-4.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	5.0-5.5	0	0	0	0	0	0	0	0		0	0	0	0	0	0
	6.0-6.5	0	0	0	0	0	0	0	0		0	0	0	0		
EG 18/82	3.0-3.5	0	0		0	0		0		0			0	0		
	4.0-4.5	0			0	0				0			0	0		
	5.0-5.5	0	0		0	0		0								
	7.5-8.0	0	0	0	0	0										0
	9.5-10.0	0	0		0	0									0	
	11.0-11.5	0	0		0	0		0		0			0	0	0	
EG 19/83	17.0-17.5 (blue clay)				0	0										
	17.0-17.5 (black clay)				0	0										
	GREY CLAY				0	0										
	BROWN CLAY				0	0										
EG 20/83	13.0-13.5	0														0 (two high load tests)
	14.5-15.0 (grey clay)					0										

Fig. 4 RECORD OF LABORATORY TESTS

(Su) at total overburden pressure, calculated using the Mohr-Coulomb criterion. Initial tangent elastic moduli (E_{tan}) have also ben calculated.

2.2.2. Consolidation Tests

Consolidation tests were carried out at the G. S. D. using 70 mm x 19 mm disc specimens in a single Wykeham Farrance rear-loading oedometer. Five loading and two unloading stages of 24 hours each were used to produce the e-logp´curves. Values of Modulus of Volume Compressibility (mv), coefficient of consolidation (C_v), Compression Index (Cc), Swelling Index (Cs) and coefficient of Secondary Swelling ($C\alpha s$). Maximum previous over-burden (Pc) and thus the Over-Consolidation ratio (O. C. R.) have been calculated using the Casagrande construction, whilst the Schmertmann construction the 'field' compression/rebound lines (see App. 3.2). In addition, two special high-pressure, double-unloading, consolidation tests have been completed at B. G. S., reaching pressures of 32 MPa (32,000 KN/m^2).

2.2.3. Index Tests

Determinations of moisture content (m), Liquid Limit (L.L), Plastic Limit (P. L.), Specific Gravity (Gs) and Particle-Size were made at G. S. D. according to British Standard B.S. 1377 (1975); the Casagrande apparatus being used for the Liquid Limit test (Test method 2B, B.S, 1377, 1975), and the hydrometer method for the particle-size analysis (Test method 7D, B.S. 1377, 1975). In addition values of Bulk Density (γ_b), Dry Density (γ_d), and Degree of Saturation (S) were determined from Triaxial and consolidation specimens.

2.2.4. Chemical Tests

Determinations of total carbonate content, total sulphate content (both acid soluble and water soluble), montmorillonite content and Free Swell (both 1 hr and 24 hr tests) were made by the Geochemical Unit of the G.S.D. Montmorillonite content was found using the methylene-blue test. Free-swell was found by drying and crushing and weighing the sample then measuring the % expansion in distilled water; results are quoted at particular moisture contents. This method approximates to that suggested by Gibbs and Holtz (1954).

2.2.5. Swelling Pressure Tests

Swelling Pressure tests were carried out at B. G. S. on selected samples. These were oedometer-type disc samples (70 mm x 19 mm) in a standard oedometer cell adapted to fit a 10kN Triaxial load frame. The test method is described in Hobbs & Horseman (1983) and incorporates an electronic feedback system to eliminate swelling strain and thus ensure accurate measurement of the swelling pressure development consequent upon immersion of the sample in distilled water. Specimens were stored in a humidity/temperature controlled room and tested at 'natural' moisture content. A series of multiple swelling pressure tests at different moisture contents were made to study the effects of drying-out on swelling.

2.2.6. Mineralogical Tests

Mineralogical analysis was made by the Applied Mineralogy Unit of B. G. S. with 25 samples of marl. The results are given in AMU Report 83/10 and summarized in Appendix 1.2. The samples were examined using x-ray diffractometry (Philips PW 1050, Co - K_α radiation) on randomly oriented, air-dried material hand-crushed to minus 100 mesh. The phases identified are given in Appendix 1.2. In addition, quartz contents were calculated by comparison with quartz peak intensities of artificial mixtures. Thermogravimetric analysis was used to determine total carbonate content (maximum) (CO_2 at 25 ml/min and 50° c/min.) based on calcite weight loss. Surface Area (S.A.) measurements in m^2/g were made using the ethylene glycol monoethyl ether (EGME) method (see Georgiou & Morgan, 1979). Montmorillonite content was calculated from values of S.A. taking a value of 800 m^2/g for pure montmorillonite.

2.2.7 Residual Strength Tests

Three residual strength tests were made at B.G.S., Keyworth, using a Bromhead ring-shear apparatus. Measurements of residual shear angle (ϕr^o) were made at various normal loads on two samples of grey marl from borehole 7/82 and one sample of grey marl from borehole 14/82.

3. GEOTECHNICAL TEST RESULTS

3.1. Index Tests

3.1.1. Atterberg Limits

The results of Liquid and Plastic Limit tests are given in Appendices 1.1 and 3.6. and also in the form of a Casagrande Plasticity Chart in Fig. 5. Liquid Limits lie in the range 38% to 101% ($\bar{x}$ = 75.8, SD = 15.3, n = 43). Plastic Limits lie in the range 10.7% to 43.7% ($\bar{x}$ = 29.2, SD = 7.1, n = 43). these results place the marl clearly in the CH or highly plastic clay group of the USCS classification (see Section 6). Five samples lie below the 'A-line' (P.I. = 0.73 (L.L.-20)) in the OH, i.e. organic, group. Two samples lie in the CI, i.e. intermediate plasticity, group. The Atterberg Limits exhibit a statistical distribution close to that obtained for 178 samples described in Hobbs & Loucaides (1982) as part of the Geotechnical Map of Nicosia database. Liquidity Indices (L. I.) lie in the range -0.4 to +0.4 ($\bar{x}$ = 0.014, SD = 0.2, n = 39). The highest values of Liquid Limit (>90%) are recorded in boreholes EG 9/82, 17/82, 18/82 and 19/82.

3.1.2. Unit Weights

Bulk Unit Weight and Dry Unit Weight have been measured on 27 samples. Dry Unit weight lies in the range 1.31 to 1.67 g/cc ($\bar{x}$ = 1.44, SD = 0.08 , n = 27); Bulk Unit weight lies in the range 1.59 to 1.96 ($\bar{x}$=1.85, SD = 0.075, n = 27) and Specific Gravity lies in the range 2.58 to 2.78 ($\bar{x}$ = 2.68, SD = 0.05, n = 20). These results (see Appendix 1.3) agree with those quoted in Hobbs & Loucaides (1982) and in Anon, (1972). Borehole 14/82 exhibits a steady decrease of Dry Unit Weight with depth between 3.0 m and 10.0 m. All boreholes show downward decreasing Dry Unit Weight between 3.0 m and 5.0 m, and a downward increasing Dry Unit Weight below 10.0 m (below 8.0 m for borehole 15/82).

3.1.3. Particle-Size Analysis

The results of P. S. A. (see Appendices 1.1., 3.6., 2.2., and Fig. 12) reveal the marl to be a slightly sandy silty clay or clayey silt. Clay

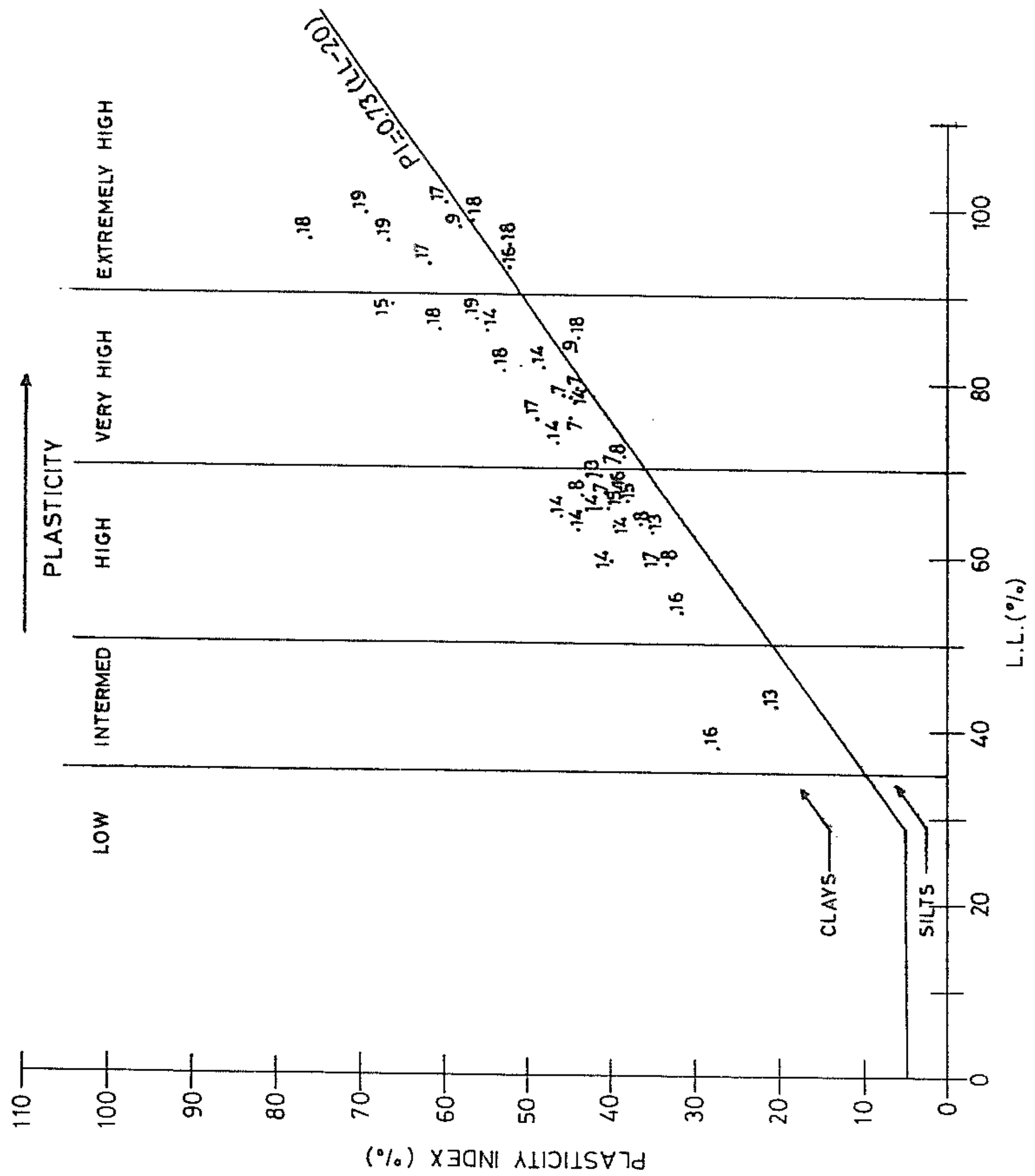


FIG.5

CASAGRANDE PLASTICITY CHART

BH's EG7/82 — EG19/83

(NUMBERS INDICATE BOREHOLE)

G.S.D.(E.Geol.) D.P. 33/83

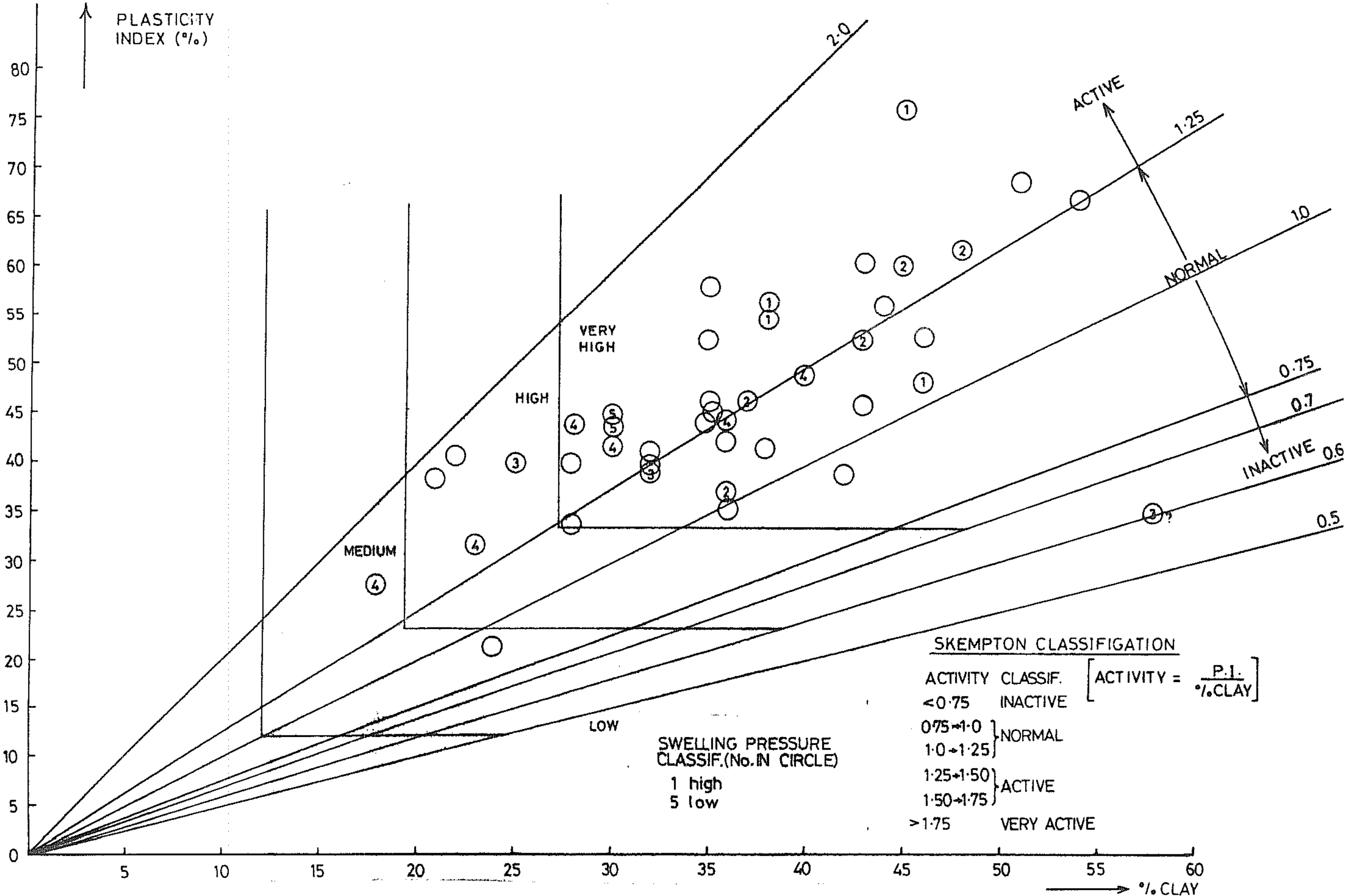
Fig. 5

percentage ranges from 18% to 63% ($\bar{x}$ = 36.5, SD = 9.1, n = 44) and silt percentage from 31% to 69% ($\bar{x}$ = 54.4, SD = 7.0). The grading curves (see Appendix 2.2.) show that the marl is well-graded to moderately well-graded, frequently having similar proportions of fine, medium and coarse silt clay. Only one sample (marly calcarenite, EG 16, 5.0) exhibits gap-grading. There is a tendency for calcarenitic marls, marly calcarenites and other marls with high carbonate contents to be generally coarser than the ordinary marls; their modes lying in the coarse end of the silt range. The Folk triangular classification (see Fig. 12) of silt, sand and clay shows the marls clustered at the silty end of the area designated 'mud' and 'sandy mud'. Those samples which stray from the cluster are the sandy marls, calcarenitic marls and marly calcarenites.

A plot of % clay fraction v. Plasticity Index (see Fig. 6) givesthe 'Activity' of the marl's clay minerals. A considerable scatter of results is seen, ranging from normal to high Activity. A general lack of correlation between Activity and other plasticity-related parameters would suggest errors in the determination of the clay content. Aggregations of clay-sized particles may not have been broken down during sample preparation (Davis, 1967) leading to an underestimation of clay content and thus an overestimation of Activity. In the case of the Keuper Marl of the U.K. (not a 'true' marl) photomicrography has shown clay plate aggregates 'clothed' with quartz particles (Barden, 1972).

3.1.4. Moisture Content

The moisture contents measured immediately after core-recovery range from 14% to 38%; the variations being due to marl type, time of year, position relative to the water table, and drilling disturbance. Generally, moisture content increases from the surface to between four and six metres depth and remains relatively constant, or increases slightly below this to depths of 18 metres or more (see Appendix 1.1 and Fig. 7). The degree of saturation varies from 80% to 106% (values above 100% being clearly in error). Moisture contents generally lie close to the Plastic Limit. In elevated, well-drained areas (e.g. boreholes 9/82 and 13/82) moisture contents lie below thePlastic Limit (thus giving negative values for Liquidity Index), whereas in low-lying areas the moisture contents are at, or slightly above, the Plastic Limit.



G.S.D.(E.Geol.)D.P.23/83

Fig. 6 ACTIVITY GRAPH FOR B.H.'s EG7/82 - EG18/82

Fig. 6

3.2. Triaxial and S.P.T. Tests.

3.2.1. Triaxial Tests

A total of 20-Multi-stage undrained, unconsolidated (UU) Triaxial tests were carried out. Values of ϕu range from 5° to 26° ($\bar{x}$ = 13.2, SD = 5.5., n = 20) and values of Cu from 50 to 330 KPa ($\bar{x}$ = 149, SD = 70.3, n = 70.3). Undrained shear strength (Su) is plotted on the borehole logs (Appendix 1.1); this is calculated from the formula:- $Su = Cu + P\tan\phi u$ where P is the estimated present total overburden pressure. Stress-strain curves and Mohr Circles are given in Appendix 2.4.

For a 'standard' soil, structural strength is independent of cell pressure, i.e. a horizontal ($\phi u = 0$) Mohr-envelope is obtained for the 'total' stress condition and a unique Mohr Circle is obtained for the 'effective' stress condition. In this study, however, we find that strength is increasing with increasing normal stress ($\phi u > 0$) in all cases. This may be due to two factors:-

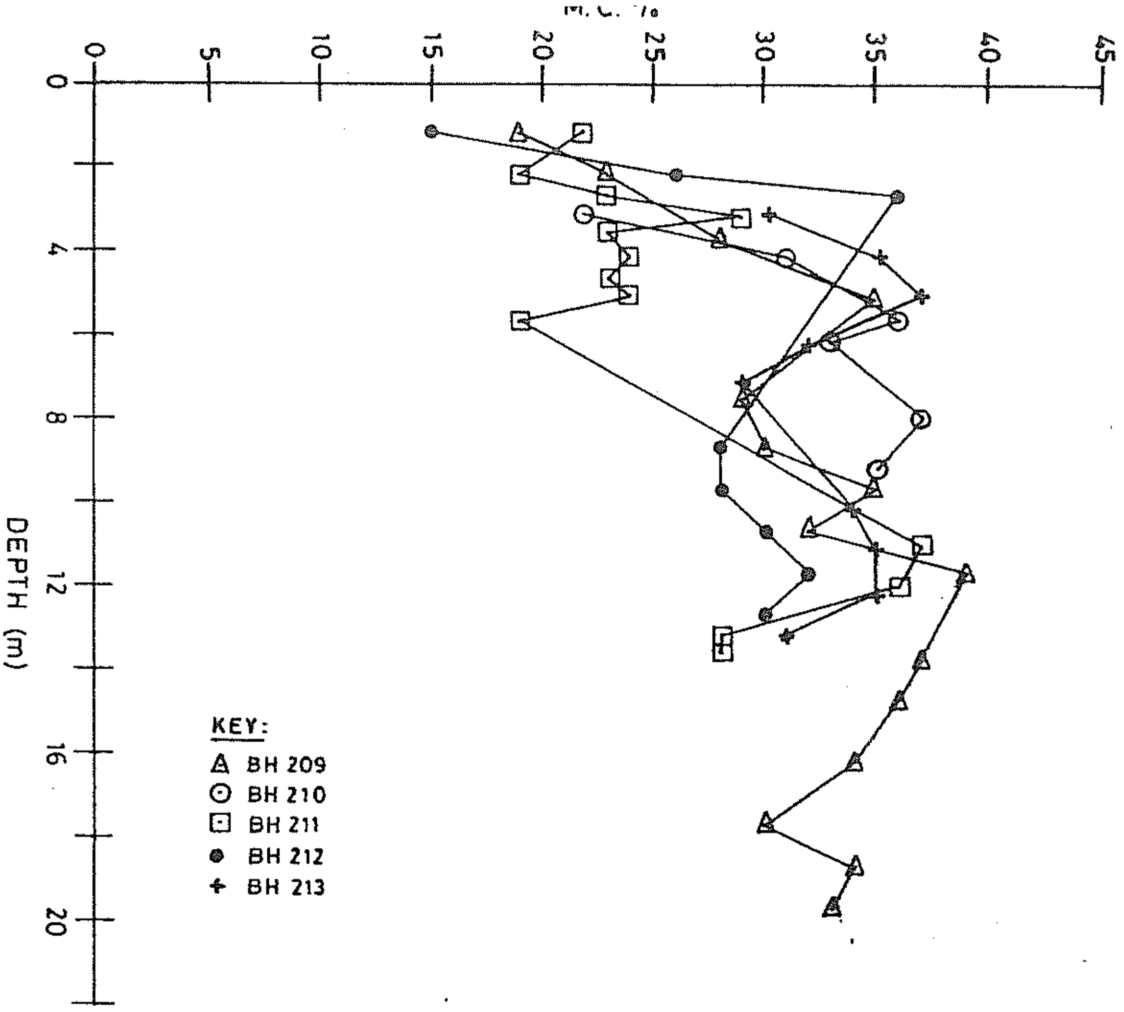
a) Partial saturation - as pressure increases air within the sample passes into solution resulting in a curved (concave downward) Mohr-envelope which levels off when the degree of saturation (S) approaches 100%.

b) Fissuring - below present overburden pressure, saturated fissured clays exhibit lower shear strength than the equivalent unfissured clay due to the closing-up of fissures during shearing. This may result in a curved Mohr-envelope similar to that for a partially-saturated sample.

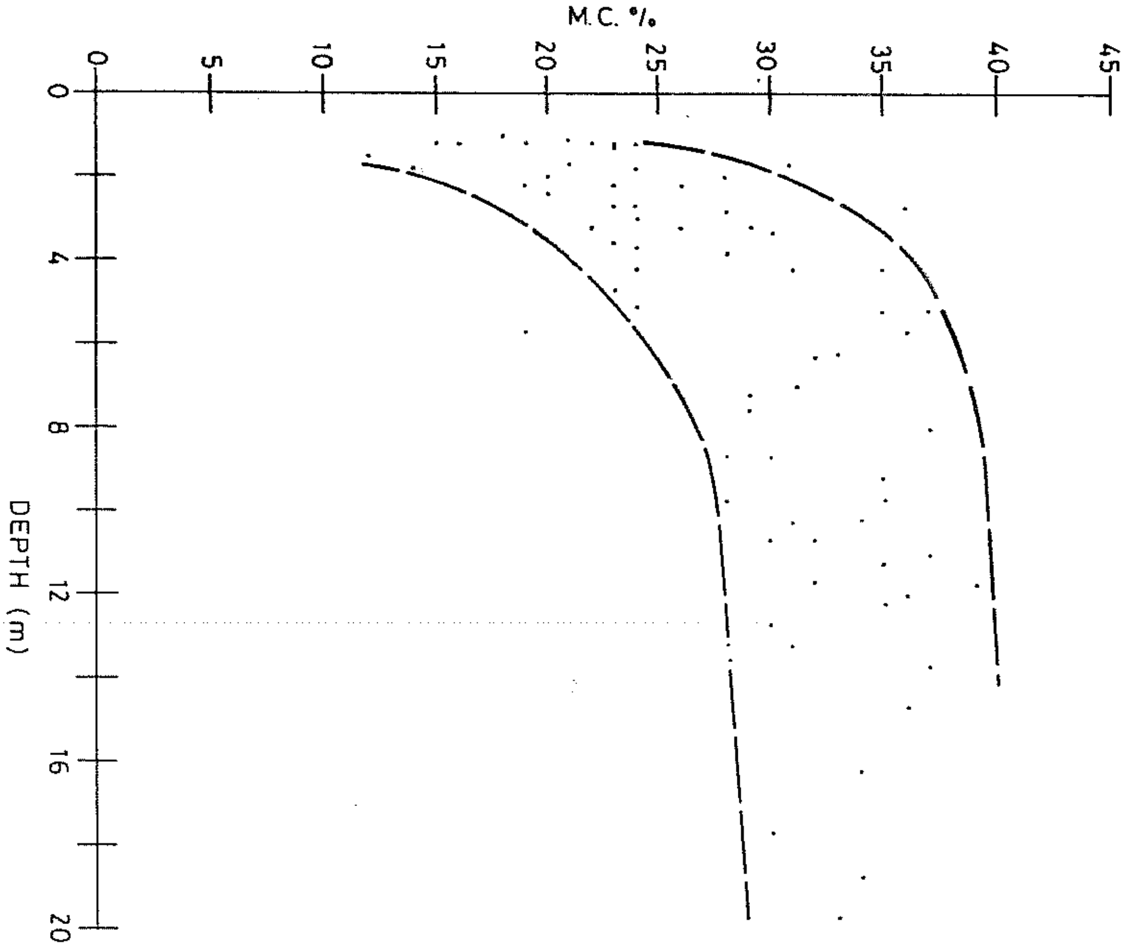
Both the above factors appear to influence the test results to some degree as $\phi u > 0$ is obtained for unfissured marls and also for saturated marls. However, there is a moderately good inverse correlation (r = -0.8) between degree of saturation (S) and angle of friction (ϕu).

3.2.2. Standard Penetration Tests (S.P.T.)

Standard Penetration Tests were carried out at one metre intervals where possible; alternating with the U4 sampling. Thus no accurate



MOISTURE CONTENT / DEPTH PROFILE FOR BOREHOLE SAMPLES FROM THE MAKARIOS STADIUM SITE INVESTIGATION (ANON., 1972)



MOISTURE CONTENT / DEPTH PROFILE FOR ALL MARL SAMPLES FROM THE MAKARIOS STADIUM SITE INVESTIGATION (ANON., 1972) comparison can be made between S.P.T. and Triaxial results due to lithological variations from one metre to the next. However, depth trends of S.P.T. are comparable with those of Su (see App. 1.1.). Generally S.P.T. values are lower below, than above, the water table e.g. B.H. EG18/82). There is not clear correlation between S.P.T. or Triaxial strength and lithology. In some cases a decreasing fines content, and decreasing plasticity, is accompanied by a decrease in S.P.T. value (e.g. B.H's EG15/82 and EG16/82) and some highly-plastic marls exhibit high S.P.T. values (e.g. B.H.'s EG15/82 and Eg18/82. In fact, a positive trend between S. P. T. and Liquid Limit is indicated. Resistance to standard penetration of the marls may be summed up as high to very high (see also Anon, 1972). The S. P. T. value is, however, closely related to the moisture content and may be unreliable in cohesive soils.

3.2.3. Residual Strength

Triaxial results show a variety of undrainedstrengths from 'soft' to 'very stiff' or 'hard' (C. P. 2004, Table 2). Generally the strength of plastic marl in an undisturbed state is high. Equally, the drained residual strengths (see Fig. 8), though based on only three samples, are high, lying in the range ϕr = 20°-30°. The Residual shear angle decreases at low values of normal stress but much less so than is the case for the highly bentonitic Moni clays (see Fig. 8). At higher normal stress the residual shear angle decreases gradually and presumably levels off at some point; Lupini et al (1981) have identified three mechanisms of residual shear behaviour: 'turbulent', 'sliding' and 'transitional' (a combination of turbulent and sliding). The values of ϕ r obtained depends on the relative proportions of platy and rounded particles. Turbulent behaviour results in ϕr values greater than 25° and sliding behaviour ϕr of between 5° and 20°. The sharp contrast in residual behaviour between the marls and the Moni clays (see Rep. No. EGARP KW/86/2), for example, is due to the high proportion of platy, low friction montmorillonite particles in the Moni clay and the dominantly silty high friction particles of the marl. In fact, the weakest of the three grey marls samples (7/82, 11.0) is more plastic than the other two (see Fig. 8). It is possible that, given more test data, a good positive correlation between Plasticity Index and residual shear angle may be found.

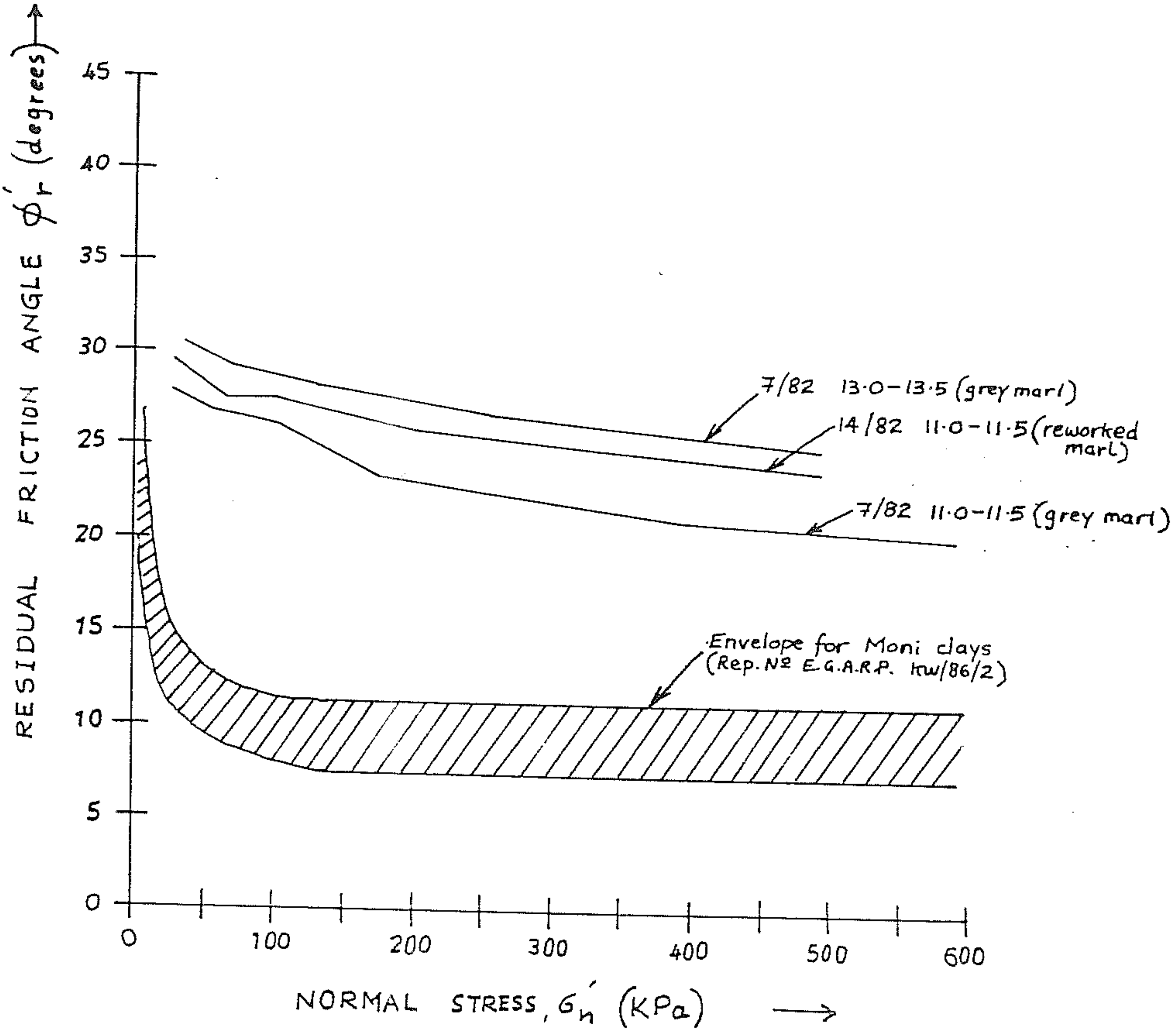


Fig. 8 RESULTS OF RING SHEAR TESTS

3.2.4. Deformation Moduli

The determination of deformation moduli in solids is subject to inaccuracies (Lambe & Whitman, 1979). The initial Young's tangent moduli, Ei, (given in App. 2.4) are affected by rate of loading, sample disturbance, sample size and other factors which affect the undrained strength. The influence of these factors on the modulus is considerably greater, however, than their influence on strength, particularly at the low stress end of the stress-strain curve. Generally triaxial tests on fissured clays give much lower values of Ei than either in-situ tests or back-analyses of settlements (Marsland, 1973). Also, the method of sampling has been found to be crucial; triaxial samples obtained from block samples may give moduli up to five times those from driven samples. Stress-relief after both drilling and extrusion in the laboratory may result in the formation of new fissures as well as the opening up of existing ones, thus resulting in a drop of modulus. Increasing the length of sample storage time also been found to reduce the modulus (Marsland, 1973).

In general, one may expect an increase of modulus with depth and a slight increase of modulus with decreasing triaxial sample size. Values of Ei obtained from large scale in-situ plate loading tests are between 2 and 5 times those obtained from conventional triaxial tests (Marsland, 1973). Variations within each class of marl are very great; for example, grey marl from borehole EG14/82 has an Ei of 28 MPa and similar marl from borehole EG7/82 has an Ei of 4.4 MPa. Similarly, the calcarenitic marls from boreholes EG15/82 and EG16/82 have Ei ranging from 7.5 Mpa to 30 Mpa. Values of Ei were plotted against O. C. R. but no correlation was found. Ladd (1964) puts forward a rather tenuous positive correlation between Ei and O. C. R. for heavily-overconsolidated clays. Values of Ei were also compared with the so-called 'equivalent modulus', 1/mv (i.e. the inverse of the modulus of volume change); Ei was found for all samples to be between one and three times the equivalent modulus.

3.2.5. Sensitivity, St

Defined as the ratio of undisturbed to remoulded strength (at the same moisture content), has not been specifically measured in this study.

However, the site investigation for the Makarios Olympic Stadium (Anon, 1972) shows clearly that the marls, in that area at least, are classified as normal to extrasensitive. Values of St range from 1.0 to 12.0 ($\bar{x}$ = 5.5, SD = 2.74, n = 27). A commonly used Sensitivity classification is: 1 → 2 slightly sensitive, 2 → 4 moderately sensitive, 4 → 8 very sensitive, 8 → 16 slightly 'quick'. The values of St are based on the results of unconfined, undrained compressive strength tests. All the samples having St>8.0 are weathered marls, but for St<8.0 there is no apparent distinction between weathered and fresh marls in terms of their sensitivity. The high sensitivity is to some extent reflected in the Low Dry Unit weight/strength ratio, but the values of St do seem rather high for a fissured, overconsolidated cohesive soil.

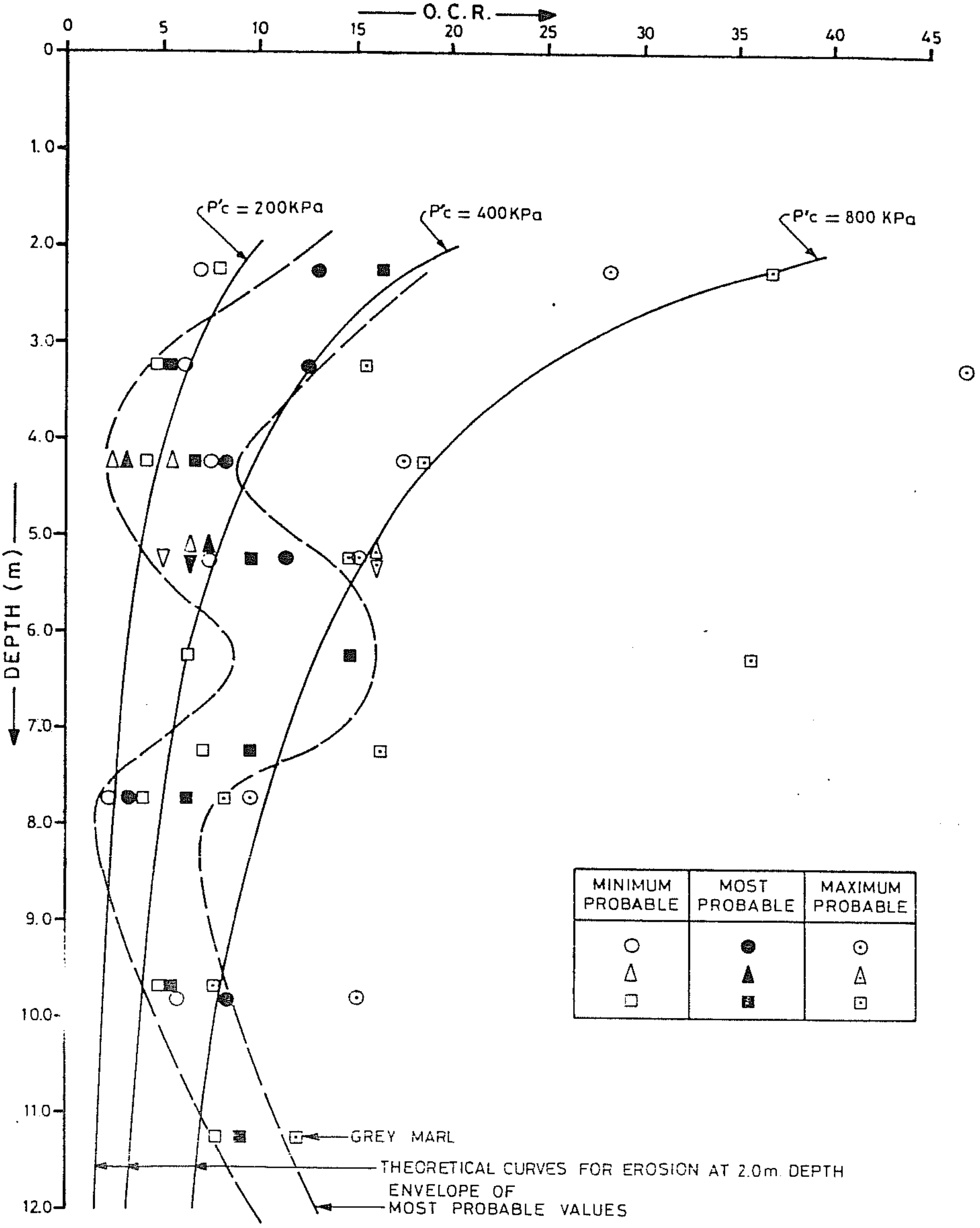
The phenomenon of sensitivity is associated with post-depositional build up of bonds due to cementation, leaching, overconsolidation. It should be noted that the maximum remoulded strength may be higher than the residual strength. However, as the Makarios Stadium data is from undrained tests, no direct comparison can be made with the results of the B. G. S. ring shear tests.

3.3. Consolidation Tests

3.3.1. Interpretation

A total of 25 tests were carried out; 17 by G. S. D. and 8 by B. G. S. (two of these were special high pressure tests). Three of the B. G. S. tests were duplicates of G. S. D. tests. The results are given in the form of e-logp′ and m_v-logp′ curves (Appendix 2.3) and the following derived parameters: Compression index Cc, swelling (or rebound) Index Cs, preconsolidation pressure (i.e. maximum previous overburden) Pc, the overconsolidation ratio O. C. R., modulus of volume change Mv and coefficient of consolidation Cv (see Appendix 1.4).

The present effective overburden pressure, Po′, has been calculated from the submerged unit weight (below the water table) and the bulk unit weight (above the water table) of the overburden as follows:-



G.S.D. (E.Geol.) 172/83 Fig. 11 GRAPH OF OVERCONSOLIDATION RATIO (O.C.R.) v DEPTH

There is a poor correlation between O. C. R. and Cs and between O. C. R. and L. I. The divergence between minimum and maximum probable values appears to decrease with depth (see EG14/82), probably as a result of decreasing sample disturbance and weathering. O. C. R. is an important parameter which, unfortunately, is very difficult to measure with any accuracy using conventional test equipment.

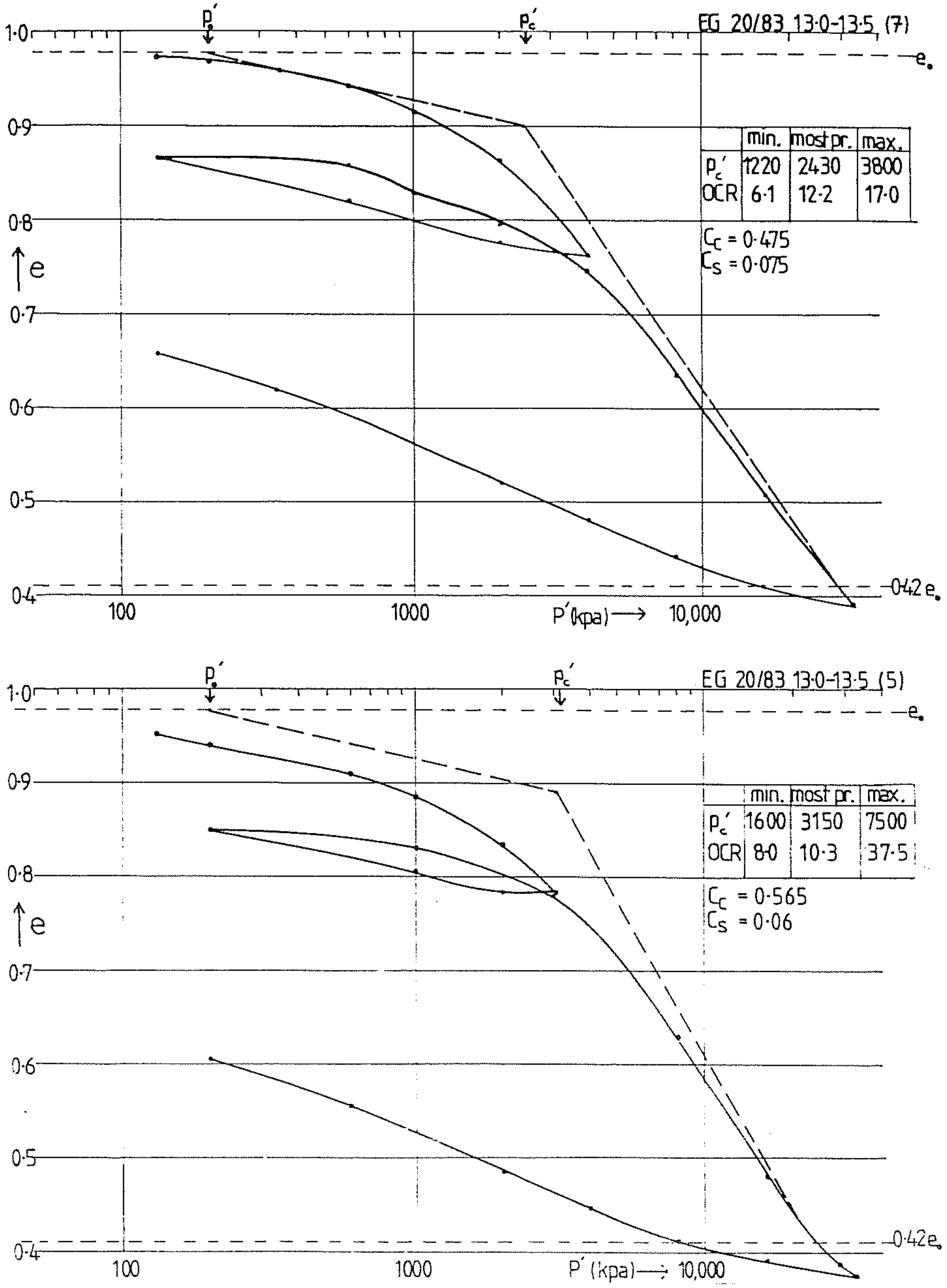
3.3.5. The Modulus of Volume Change, Mv($\propto \Delta e/\Delta p$) decreases with increasing pressure (see Appendix 2.3). Curves for each borehole tend to converge at high pressures (see Sridharan & Allam, 1982); (borehole EG14/82 is a good example) despite widely differing Mv values at low pressures (i.e. below 300 KPa). Sample EG14, 7.5 deviates from the general pattern by having a peak at 600 KPa; the reason for this is unclear. Samples EG16, 5.0 and 6.0, which are carbonate-rich marls, exhibit very large drops in Mv with increasing pressure.It has been suggested (Sridharan & Allam, 1982) that the convergence of Mv values with increasing pressure is due to the disruption of cementation/aggregation bonds leading to a similarity in the behaviour of those soils having basically the same constituents.

Curves of Cv against log pressure (not shown) are highly irregular and no pattern of behaviour could be evinced from them. This is entirely in keeping with previous experience in measuring Cv. It was noted, however, that samples EG17 3.0, 4.0 and 5.0 exhibited almost identical cv-logp curves and very little change in Cv between 100 and 1000 KPa pressure. Also, sample EG16, 6.0, a carbonate-rich marl, had a uniquely linear Cv-logp plot.

3.3.6. Permeability, K, calculated using the formula:- $k = m_v c_v \gamma w$ is reasonably uniform throughout except for this lowest consolidation pressures where values of k are high. Permeability of the marls lies in the range $10^{-5} \rightarrow 10^{-4}$ cm/sec (i.e. $10^{-2} \rightarrow 10^{-5}$ darcys). No distinction in permeability appears to exist between the various types of marl between marls at different depths.

3.3.7. High-pressure Consolidation

Two special high-pressure consolidation tests have recently been carried out at E.G.A.R.P. using a Denison 15-ton testing machine adapted as



EG 20/83 13·0-13·5 (7)

	min.	most pr.	max.
p_c'	1220	2430	3800
OCR	6·1	12·2	17·0

$C_c = 0{\cdot}475$
$C_s = 0{\cdot}075$

EG 20/83 13·0-13·5 (5)

	min.	most pr.	max.
p_c'	1600	3150	7500
OCR	8·0	10·3	37·5

$C_c = 0{\cdot}565$
$C_s = 0{\cdot}06$

Fig. 12 HIGH PRESSURE CONSOLIDATION TESTS
VOIDS RATIO (e) v Log PRESSURE (P')

an oedometer to take standard 76 mm disc samples. Pressures of 32,000 KPa were attained during multi-cycle tests (see Perloff & Baron, 1976). The resulting e-logp´curves are given in Fig. 12. The suprisingly high values of Pc and O. C. R. obtained from these curves throws some doubt on the efficacy of the normal 'low pressure' consolidation tests. It is possible that the 'virgin' or normally-consolidated portion of the low-pressure e-logp´curves is never reached and that the values of Pc and O. C. R. are lower than they should be. However, the 'high pressure' tests are, to date, limited to two samples from 13.0 metres which may anyway have higher Pc and O. C. R. being at a greater depth than the 'low pressure' test samples. 'high pressure testing of shallow samples will hopefully resolve this question.

3.3.8. Secondary Consolidation

Values for the coefficient of secondary consolidation, c_α, range from 0.0002 to 0.0121. In general there is an increase in c_α, with each pressure increment. In some cases the c_α levels off at the 4th and 5th increment of load whereas elsewhere c_α is apparently still increasing at the highest increment. This supports the conclusion (section 3.3.7) that the virgin portion of the e-logp curve is not reached in many of the low pressure consolidation tests (Lambe & Whitman, 1979 p.413). However, graphs of c_α vs. logp (see Appendix 2.6) do in many cases show a distinct upturn at the point of maximum previous overburden Pc´, as might be anticipated.

3.4. Swelling Pressure Tests

3.4.1. Results

A total of 20 swelling pressure tests were carried out at B. G. S. using automatic apparatus, specially developed within E.G.A.R.P., which measures the pressure developed, on immersion in distilled water, of an 'undisturbed' oedometer-type sample for a 'zero' volume change condition (actual volume change ± 0.005 mm). The values of maximum swell pressure (Psw) range from 3.7 to 77.5 KPa; which may be considered to be low when compared with previous results, albeit using different methods, on marls (Katzir & David, 1969; Komornik & David, 1969; Erol & Dhowian, 1982).

3.4.2. Factors Influencing Swelling

The swelling pressure of a marl is dependant on the following factors:-

a) Cementation i.e. that proportion of carbonates and other salts contributing to cementation will tend to reduce swelling pressures (Sridharan & Allam, 1982; Hardy, 1965).

Yong and Warkentin (1975) found that the presence of iron salts markedly reduced swelling (but see Warkentin & Bozozuk, 1961).

b) Aggregation of clay-size particles into 'crumbs' affect the mobilization of full swelling potential as well as other mechanical properties depending on grain-size and surface area.

c) Initial moisture content and dry density determine what percentage of the swelling potential is actually mobilized. Also seasonal desiccation can result in cementation and aggregation.

d) Remoulding or disturbance of marl can have a strong influence on swelling pressure due to the breakdown of cementation, preferred particle orientation (disrupted by disturbance) and removal of any effects of stress-history (e.g. overconsolidation). Remoulding tends to reduce swelling pressure (Warkentin & Bozozuk, 1961; Yong & Warkentin, 1975).

e) Stress-history: overconsolidation in the laboratory has been shown (Mesri et al, 1978) to increase the rebound of consolidated samples. Also it is likely that overconsolidation in the field will result in preferential orientation and closer packing of clay platelets (Horseman et al, 1983; Komornik & David, 1969) resulting in increased welling pressures. This is not borne out by the test results however, where a negative trend is suggested between swelling pressure and O. C. R. (but see (d) above).

f) Clay Mineralogy: The type and amount of clay mineral present, as well as the pore-water salt concentration, will have an important effect on the swelling behaviour (Yong & Warkentin, 1975). Pure montmorillonites, and in particular sodium montmorillonites, will produce large swelling pressures (Pusch, 1980; Grey et al, 1980), due to their very large specific Surface Areas. The presence of calcium montmorillonite in the marls tested, ranging from 8% to 29% (see section 4.3), does result in higher swelling pressures although the correlation is poor (see Fig. 13); the contribution of the other factors, listed above, is probably the reason for this.

g) Macrostructure: The presence of discontinuities, whether open or filled, probably affects the swelling behaviour in as much as pore-fluid transmission and differential swelling will influence the rate and, possibly, the amount of swelling pressure. Open fissures will tend to dissipate swelling pressures which cannot thus be recorded. This behaviour may be representative of field conditions. The material infilling many fissures, a light-grey plastic clay, is likely to have different swelling properties from the bulk brown marl. This veining can be clearly seen in the photographic log (see Appendix 1.1) and is discussed in section 5.1.

3.4.3. Correlations with Swelling Pressure

Swelling pressures have not been found to correlate well with Dry Density, Activity or Plasticity Index as might be expected (Komornik & David, 1969; Seed et al, 1962; Holtz & Gibbs, 1954). However, Hardy (1965) found poor correlations between swell and Atterberg Limits and Activity, which he attributed to alteration of structure in the tests. A negative linear correlation is suggested by Erol & Dhowian (1982) between swelling pressure and liquidity index (log) for active Saudi Arabian clays. A poor correlation ($r = -0.43$) is found for the marls, however, (see Fig, 14). A slightly better positive correlation is found between swelling pressure and swell index. Cs, obtained from the consolidation test (see Fig. 13). Attempts at multi-regression analysis to relate swelling pressure to more than one index parameter have proved unsuccessful. Komornik & David (1980)

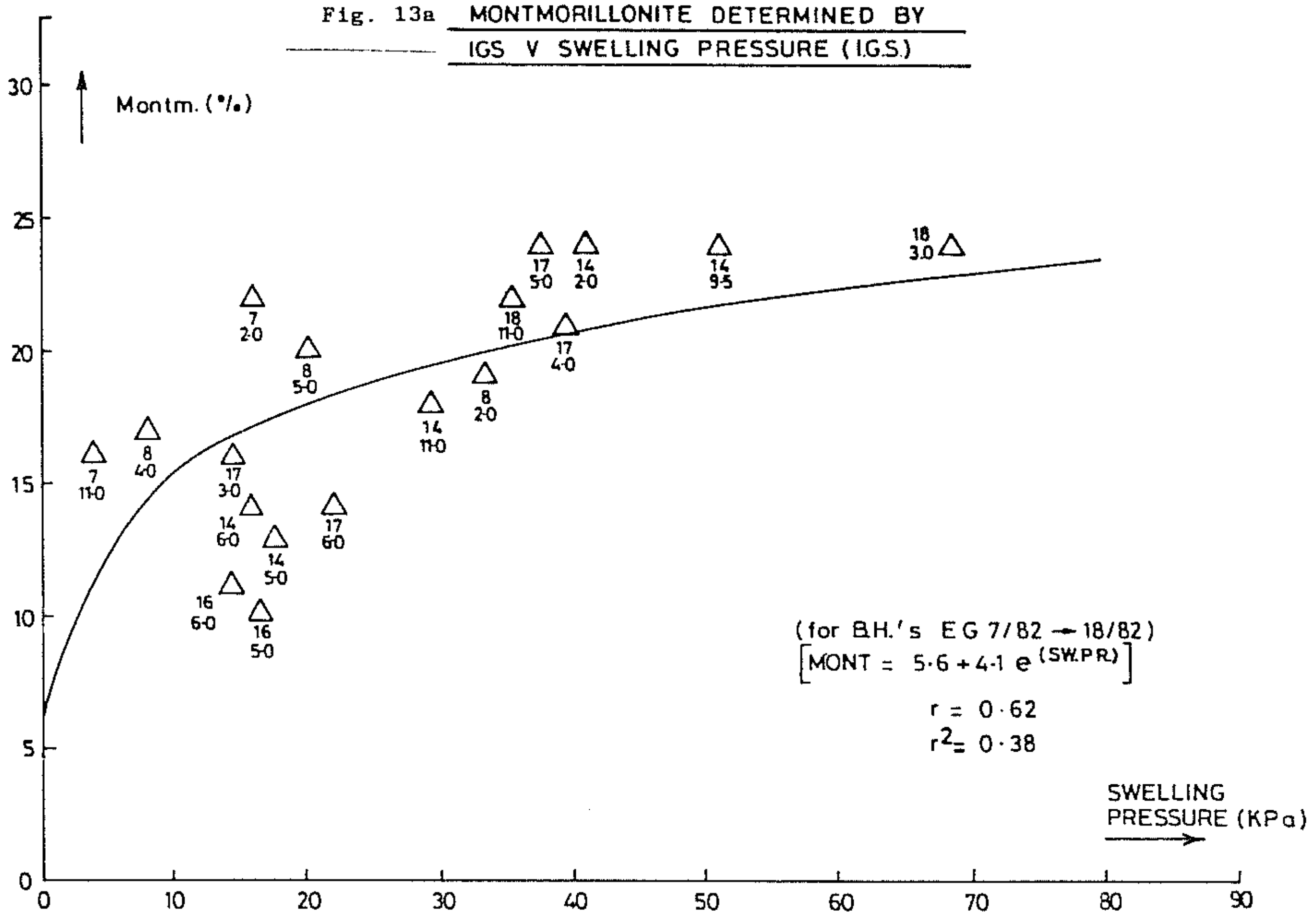


Fig. 13a MONTMORILLONITE DETERMINED BY IGS V SWELLING PRESSURE (I.G.S.)

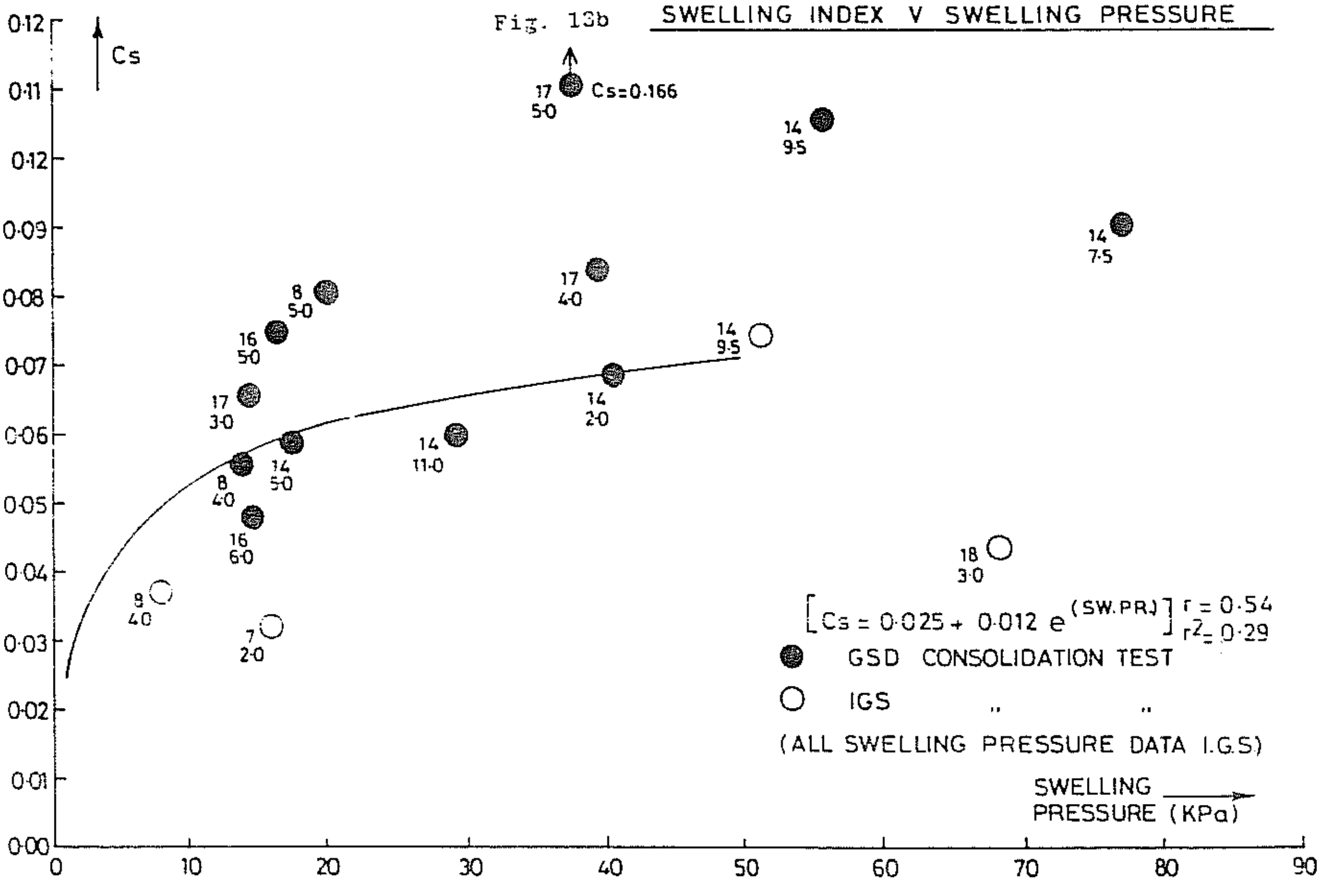


Fig. 13b SWELLING INDEX V SWELLING PRESSURE

have apparently achieved such a relationship for Israeli marls using the following formula:-

$$\log P = 0.0208\ (LL) + 0.665\ (\gamma_d) - 0.0269\ (M/C) - 1.868$$

Applying this formula to the Nicosia Marls resulted in a coefficient of correlation r = 0.56 between measured and calculated swelling pressure.

3.4.4. <u>The Mechanisms of Swelling</u> are complex and not fully understood, (Hobbs et al 1983). The development of a swelling pressure at constant volume, and equally the unrestrained swelling, on wetting of a sample is due to three factors:

a) Elastic rebound on removal of stress; the proportion of this factor actually measured in the laboratory is probably small. It is more significant at lower moisture contents.

b) Hydration (or crystalline swelling) is the adsorption of monomolecular layers of water on planar surfaces of the clay crystal lattice. This becomes significant in swelling at low moisture contents. Hydration can occur at very high confining pressures.

c) Osmotic swelling is due to a high concentration of ions held by electrostatic forces in the vicinity of clay surfaces. This "structured" water layer may persist up to 100% from the surface of a clay platelet. In the case of montmorillonite-rich clays, which have high surface areas, osmotic swelling becomes a major factor. This is particularly true where preferential orientation of clay platelets occurs (due, for example, to overconsolidation). The swelling process follows a logarithmic curve with time (see Appendix 2.5) and reaches a maximum when the repulsive forces balance either the attractive physico-chemical forces (in the case of unrestrained swelling) or the reaction of the applied load in the case of the swelling pressure test.

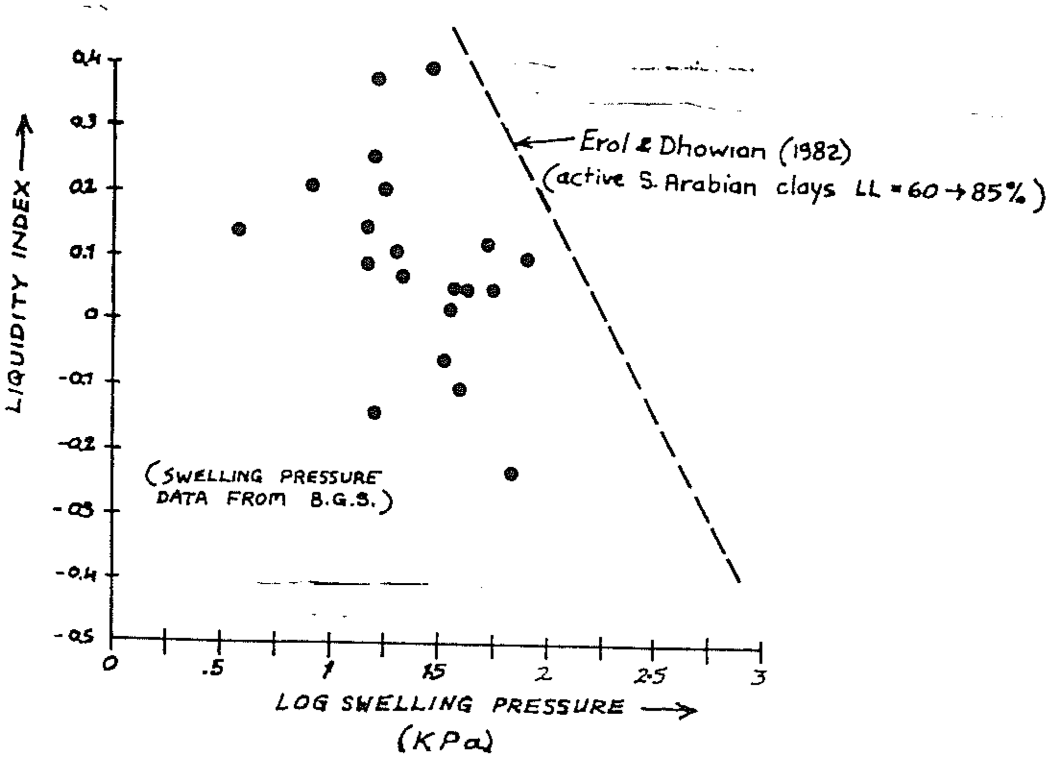


Fig. 14a GRAPH OF LIQUIDITY INDEX v Log SWELLING PRESSURE FOR B.H.'s EG7/82 - EG18/82

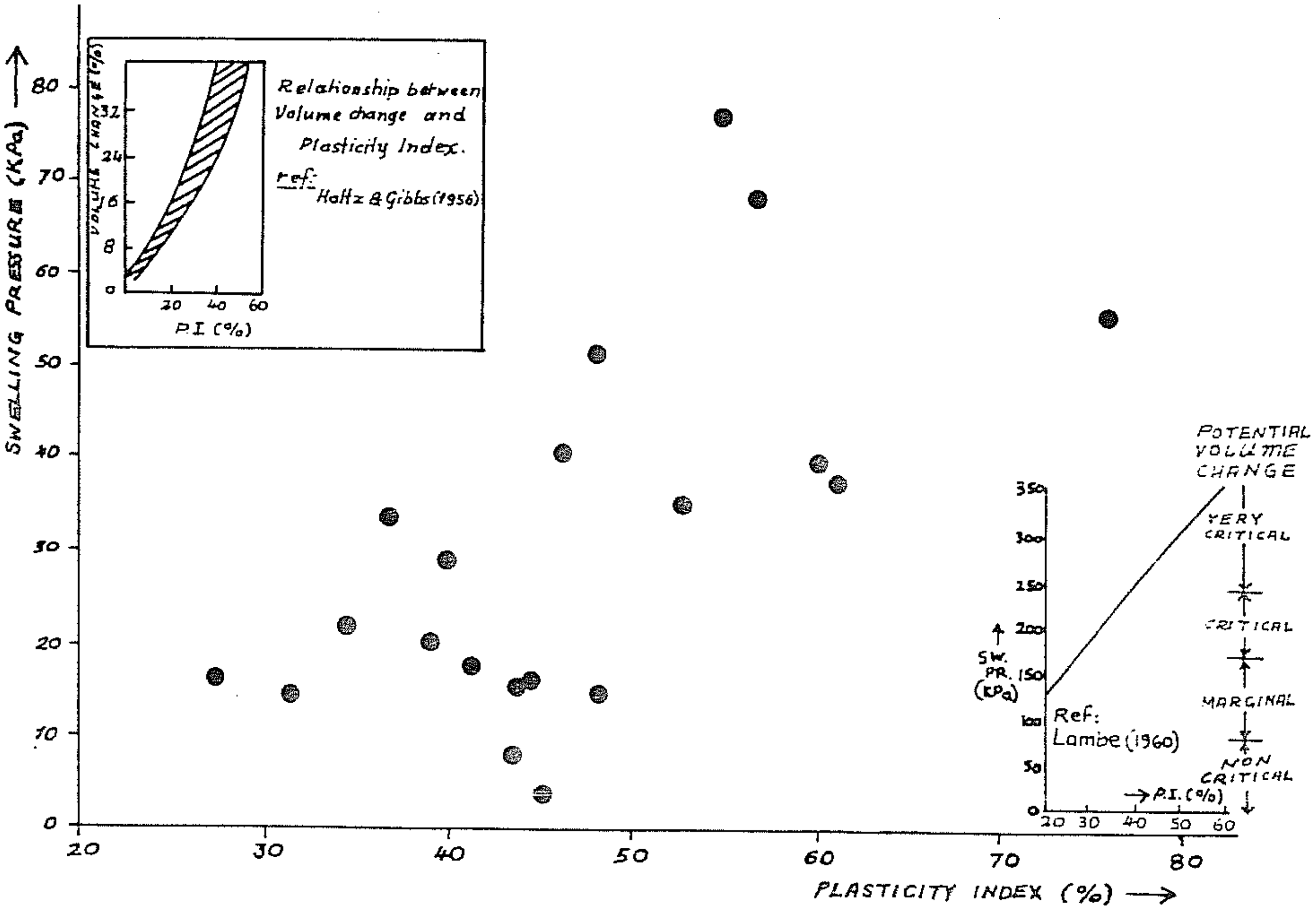


Fig. 14b GRAPH OF SWELLING PRESSURE v PLASTICITY INDEX FOR B.H.'s EG7/82 - EG18/82

Fig. 14

3.4.5. Interpretation

The direct measurement of small swelling pressures is dependent on the full pressure being transmitted to the boundaries of the sample. In fact, joints and pockets of coarse or loose material may 'absorb' some part of the total pressure developed. This would be particularly applicable to laminated, sandy and fissured marls.

A logarithmic increase in swelling pressure with decreasing moisture content is clearly demonstrated in Fig. 15. This behaviour is due largely to osmotic swelling at the moisture contents used, which are well above the shrinkage limit. During periods of drying, shrinkage occurs as the result of a decrease in the osmotic repulsion forces and consequently a moving together of the clay platelets caused by the now dominant Van Der Waals and Coulomb forces of attraction, (see Horseman et al 1982). An increase in moisture content, due either to saturation or ingress of water vapour, causes a reversal of this process resulting in swelling.

The build-up of swelling pressure with time is shown in Appendix 2.5. Maximum pressure is generally reached between half an hour and one hour, with the exception of samples from borehole EG 18/82, which peak at between 2 and 5 hours. After five hours no samples showed genuine increases in swell pressure. Higher peak swelling pressures do not necessarily imply longer swelling times (e.g. boreholes EG 14/82). Times to reach peak pressure are suprisingly low when compared with other cohesive soils (Yong & Warkentin, 1975) which may take days or even weeks. There is a moderately good positive correlation between swelling pressure and plasticity Index (r = 0.66). The swelling pressures are nevertheless low when compared with those for soils of similar plasticity. Comparisons with the literature are difficult, however, due to differences in the testing technique. The complexity of the factors affecting swelling, listed in section 3.4.2, make a regional assessment of swelling behaviour difficult. Clearly, some samples have a higher potential for swelling than others, irrespective of the moisture content, but these seem to occur as thin horizons, usually of high plasticity within lower-swelling deposits, as can be see from the wide variations within

Fig. 15 GRAPH OF Log SWELLING PRESSURE (Sw.PR.) v MOISTURE CONTENT (M/C)

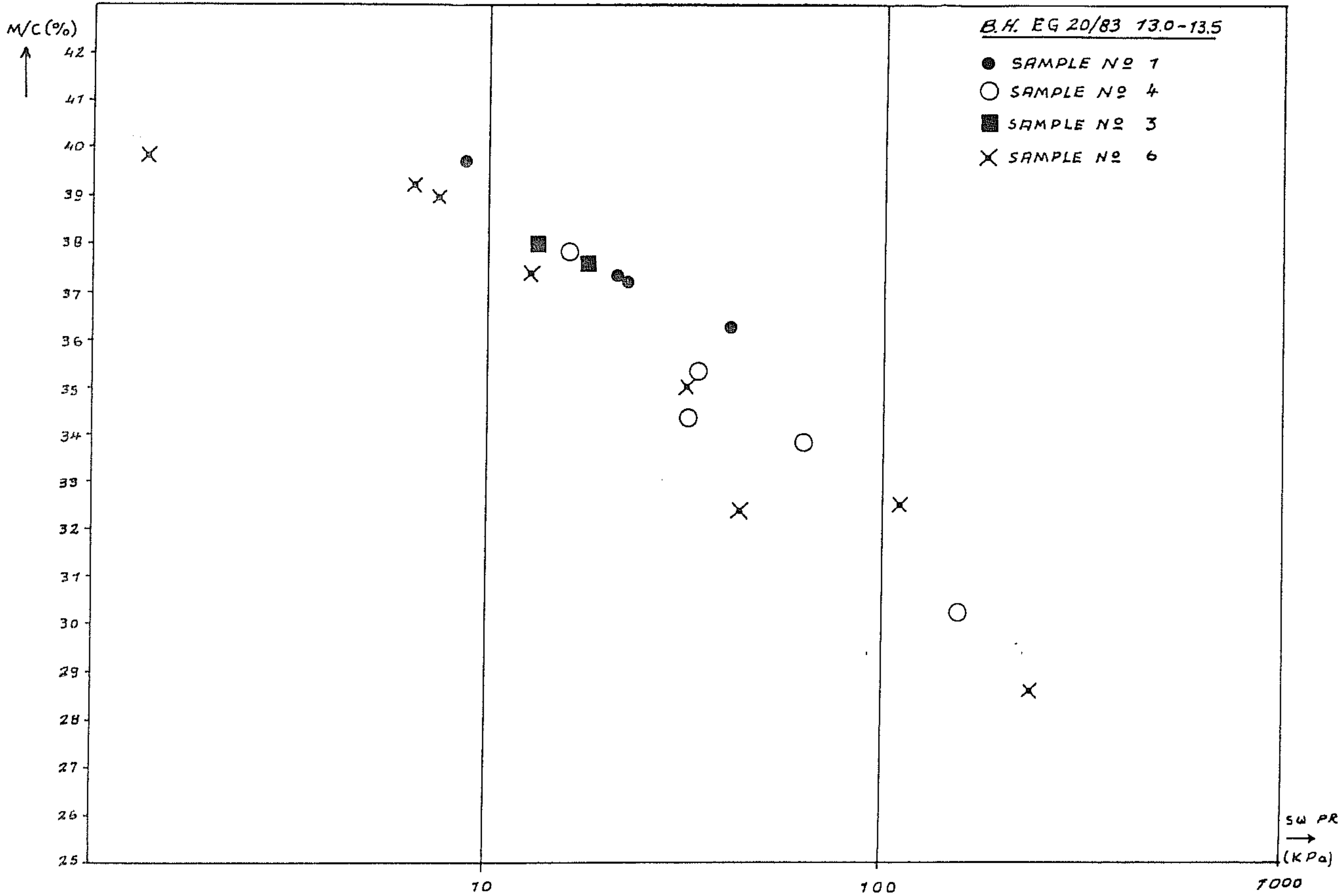


Fig. 15

each borehole. The notion that some areas of Nicosia are "high-swelling" and others not is an over-simplification which is not borne out by the results. All the samples with swelling pressures in excess of 35 KPa occur in boreholes, EG 14/82 (Lykavitos), EG 17/82 (Ayios Nicolaos) and EG 18/82 (Ayia Varvara). Unfortunately, samples from boreholes EG 15/82 (Productivity Centre), reputedly an area of "high-swelling" were unsuitable for testing.

Samples from the western part of the study i.e. "Apalos" marls (boreholes EG 7/82, EG 8/82 and EG 13/82) generally exhibit low swelling pressures (i.e. 35 KPa).

The E.G.A.R.P. swelling pressure test is in its prototype stage of development and thus is subject to certain problems, in particular electrical "drift" as shown by the "apparent" increase in swelling pressure of sample EG 7/82, 11.0 beyond 4 hours duration. More significant than the equipment problems, however, are those due to sample disturbance (in particular disturbance which allows swelling to take place prior to the test), moisture content changes during transport, storage, and testing (which affects both pore fluid viscosity, hence permeability; and also electrical drift characteristics). The test does succeed in measuring the true swelling pressure developed by the <u>sample</u>. To what extent this reflects the true swelling pressure of the in-situ material is, as yet, unclear, due to a total absence of field swelling data.

4. MINERALOGICAL AND CHEMICAL TEST RESULTS

4.1. X-Ray Diffractometry

The tests carried out at B. G. S. are described in section 2.2.6. The results are shown in Appendix 1.2. They reveal a uniformity of mineral content with only minor variations. Calcite, Calcium montmorillonite and quartz are present throughout, with small quantities of feldspar, dolomite and mica present only in some samples. Gypsum was found in only two samples, both of which have high carbonate contents (EG 16, 6.0 and EG 17, 6.0).

There are no overall trends with depth or location as far as these results are concerned. Total carbonate content (B. G. S.) ranges from 20% to 58%. Calcium-montmorillonite content (B. G. S.) ranges from 10% to 31%. The three grey marl samples (EG 7 11.0 and 13.0 and EG 14, 11.0) do not differ mineralogically from the brown marls (but see Section 4.2.). Samples described as "marly calcarenites" or "calcarenitic marls" do, in most cases, have high carbonate contents (>50%). Samples with either high carbonate or high montmorillonite contents are not confined to any particular area of the Nicosia marl outcrop.

A ternary diagram of carbonate/clay/quartz (and others) is shown in Fig. 16. This shows that the marls are grouped centrally with the exception of EG 9, 3.0. There is, however, a problem in that not all the clay fraction (<0.002 mm) comprises clay minerals as can be seen from the plot of montmorillonite content v % clay fraction (Fig. 17). All samples have between 40% and 75% of their total fraction as montmorillonite.

The remainder of the clay-size fraction must be taken up by carbonate and other minerals. The generally high values of Activity (see Fig. 6), however, suggest low contents of inactive components such as carbonate in the clay fraction.

Dolomite is a product of the metasomatic action of magnesium-bearing waters on calcium carbonate. A high feldspar content would indicate a proximity to the parent rock. Only sample EG 7, 2.0 has a high feldspar content.

Fig. 16 TERNARY CARBONATE AND PARTICLE SIZE CLASSIFICATIONS FOR B.H.'s EG7/82 - EG18/82

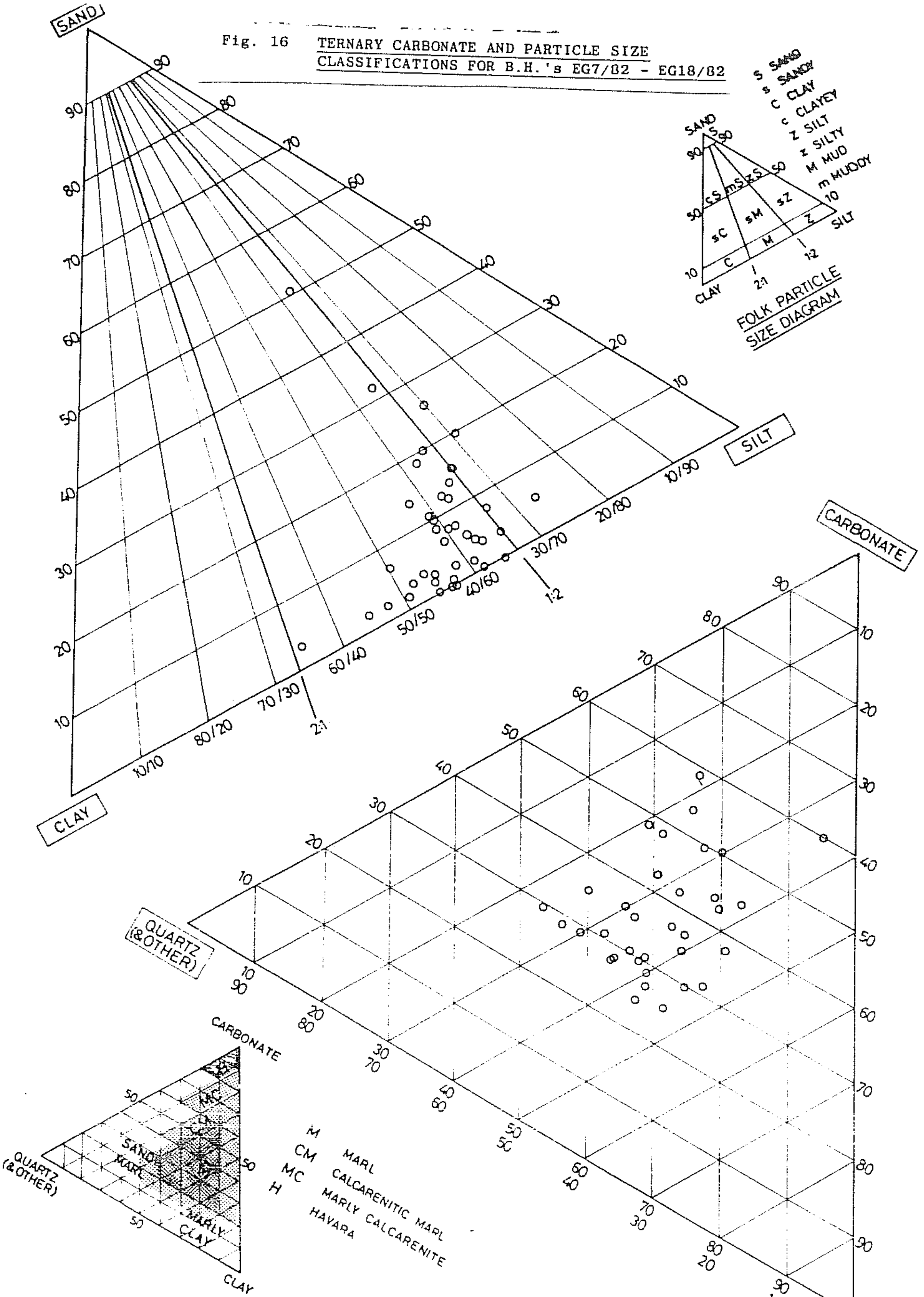
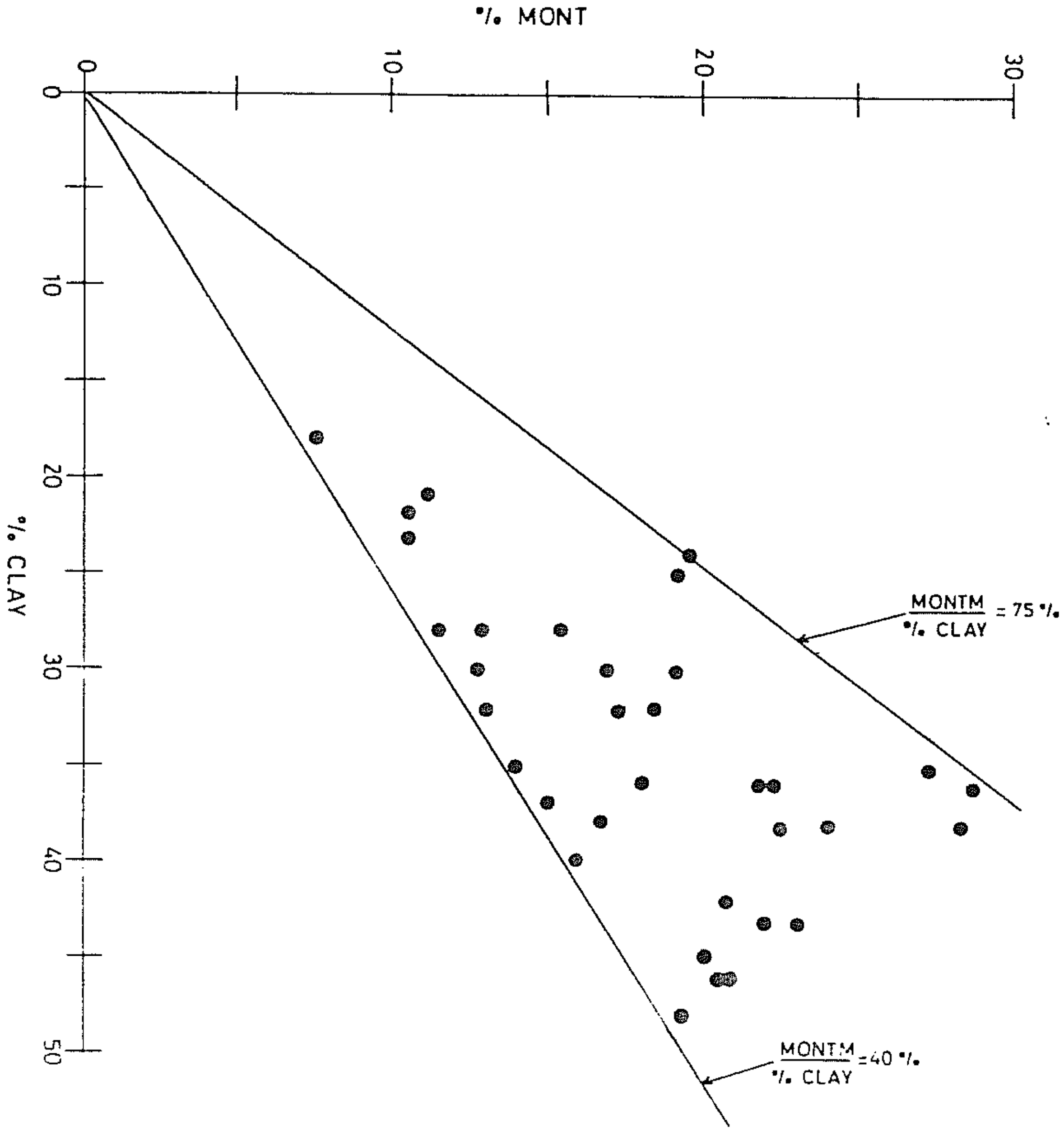


Fig. 16



MONTMORILLONITE CONTENT (G.S.D.) v CLAY FRACTION

BH's EG 7/82 → EG18/82

Fig. 17

4.2. Chemical Tests

Chemical analyses for carbonate, sulphate and montmorillonite content are given as depth profiles for each borehole in Appendix 2.1. There are some discrepancies between the montmorillonite and carbonate contents obtained by B. G. S. from x-ray diffractometry and by G. S. D. from chemical tests, (r = 0.85 for B. G. S. - G. S. D. carbonate correlation and r = 0.85 for B. G. S. - G. S. D. montmorillonite contents) due to the difference in test method.

Two types of sulphate test were carried out:

a) acid soluble,

b) water soluble.

Sulphate contents lie below 0.6% with the exceptions of EG 7/82 below 6.0 m, EG 14/82 below 10.0 m and EG 16/92 above 5.0m (see Appendix 2.1). The three samples of "grey" marl (EG 14, 11.0; EG 7, 11,0) and EG 7, 13.0) have significantly higher total sulphate contents (2.74%, 2.07% and 2.68% respectively) than the "brown" marls, whilst their water soluble sulphate contents remain low (<0.3%). Also the X-Ray analysis has not detected any gypsum in the "grey" marls. Thus it would appear that the high sulphate content in the "grey" marl is not due to a soluble sulphate such as calcium or magnesium (gypsum) but rather to a non-sulphate transition-metal sulphate such as iron sulphate. C.P. 2004 (1972) states that for total sulphate > 0.5% and soluble sulphate > 0.25% some form of sulphate resisting cement will be required in all cases.

It is not clear whether the high sulphate content is characteristic of the "grey" marl or simply due to the proximity to the weathering, and water-movement horizon of the "grey"/"brown" marl contact.

4.3. Montmorillonite

Montmorillonite is the high-alumina end member of the smectite group of expanding clay-lattice minerals, carrying both silica and alumina in solution. In acid solution ($pH \simeq 4$) the solubilities of silica and alumina are such that relatively much alumina and relatively little silica are present, thus favouring the formation of kaolinitic material (Al_2O_3: SiO_2 =

1:2); in alkaline solutions (pH=8-9) much more silica is present thus promoting the formation of montmorillonite (Al_2O_3: SiO_2 = 1:4); calcite is deposited at pH 7.8. Generally calcium favours the formation of smectite and in marls, calcium must be removed before there is an alteration of primary silicates; carbon retards the disintegration of primary silicates. Smectites are produced from the prolonged weathering of alumina-silicates (particularly calcic feldspars) in a reducing environment or one of low rainfall (Montmorillonite has an Si:Al ratio of 2:1). Smectites are derived from basic or ultra-basic igneous rocks containing considerable proportions of magnesium. Calcium montmorillonite may be produced by base exchanges from sodium montmorillonite or directly from a parent rock containing calcic plagioclase such as anorthite, or ferromagnesian minerals. Desert soils and zonal aridic soils (rainfall $<$ 0.65 m/yr.) may contain smectite and illite as well as attapulgite, palygorskite and sepiolite (found in S. African and Israeli marls). Feldspars weather readily to smectite whereas quartz remains unaltered by weathering or transport. Smectite itself alters to mica with time and is seldom found in deposits earlier than Mesozoic. Montmorillonite alters to illite and chlorite by potassium and magnesium fixation respectively, particularly in a marine environment and also with increasing depth of burial. Smectite is less evident below 1,000 metres and very unusual below 3,000 metres.
Ducloz (1964) describes the marl of the Nicosia Formation as "massive or poorly-stratified and composed of very angular grains of pyroxene, plagioclase, calcite and magnetite.....it represents the ultimate comminution of debris eroded from the igneous rocks of the Troodos Massif".

4.4. Carbonate

Calcium and to a much lesser extent magnesium carbonate form a significant proprtion of almost all deposits in the Nicosia area including the marls. Carbonate contents of the marl range from 20% to 58%. The carbonate rich marls include the so-called "marly-calcarenites" and "calcarenitic marls" found in boreholes 7, 15 and 16. The degree of cementation of a marl is not necessarily indicated by the carbonate content. Induration can occur concurrently with deposition and marls of identical composition may occur in both cemented and uncemented form within short lateral and vertical distances (see Fookes & Higginbottom, 1975). The ability of any one geotechnical parameter to identify cementation is limited. The relatively high values of sensitivity (see section 3.2.5.) however, point to a loss of strength with disturbance which may result from a breakdown of cementation. Leaching (i.e. movement of soil-water by capillary and surface evaporation) is clearly responsible for the formation of the "kafkalla" duricrust and "havara" secondary carbonate found at, or near to, the ground surface, (Everard, 1963). However, the role of leaching specifically, or post-depositional water movement in general, in the distribution of carbonate within the marl is unclear. Dry density is generally fairly low, but this is not related specifically to the carbonate content. Carbonate-rich marls contain less water (r = 0.71 for m/c v CARB) and less clay minerals (r = 0.73 for MONT v CARB). No correlation is found between carbonate content and plasticity index which suggests that a proportion of the carbonate is of silt and clay size and having no plastic properties thus "dilutes" the Activity of the marl. In fact, a weak positive correlation (r = 0. 51) is found between carbonate content and Activity, a fact which is not readily explained.

5. WEATHERING AND STRUCTURE

5.1. Weathering

The Nicosia marls may be divided into the "grey" marl and the overlying "brown" marl. The thickness of the brown marl ranges from about 5m to 20m in the Greater Nicosia area. Little information is available on the geotechnical or chemical nature of the grey marl due to the fact that site investigation boreholes do not usually reach these depths. Indications to date are that the grey marl has been primarily weathered from the surface to form the brown marl and that the brown marl has subsequently undergone leaching, deformation and secondary weathering. The colour change from grey to brown is a result of oxidation of iron compounds ($Fe^{2+} \rightarrow Fe^{3+} + e$) in particular iron oxide. Microfracturing of the brown marl has followed this weathering process, and subsequently secondary alteration has spread from the fissures as a result of water movement. The process may be summarized as follows:

a) Oxidation weathering. This penetrates to some depth partly depending on the drainage patterns, topography, climate, etc..

b) Erosion and stress relief. These probably occur simultaneously and in stages. The stress relief results in fissuring of the overconsolidated marl allowing ingress of water.

c) Secondary weathering. Movement of aggressive groundwater through the fissure system leads to alteration of the brown marl adjacent to the fissures. Transport of fine-grained material into open fissures or drying cracks may also occur in marls close to the surface.

Examination of core from boreholes EG 19/83 and EG 20/83 (see Appendix 1.1) has revealed two kinds of secondary weathering:-

a) Fissures, some of which show slickensiding and small shear displacement of the order of $0.1 \rightarrow 1.0$ cm., in "veins" of light grey plastic clay. Two phases of alteration are sometimes seen in which a darker grey clay is surrounded by an earlier lighter-coloured clay (e.g. EG20/83, 5.5-6.0). The light grey clay in the "veins" or fissures may be the effect of reducing conditions on the brown marl in-situ as a result of water-logged conditions during say a pluvial cycle; this is analogous is "gleying" (Bunting, 1965) and may represent a secondary stage of weathering post-dating the formation of the brown marl. Alternatively, a movement of grey clay into open fissures may have occurred as redeposition following a period of drying. Indeed the "light grey clay" has been shown to have significantly higher liquid limits and % clay contents than the surrounding marl.

b) The concentric banding seen in boreholes EG 19/83 and EG 20/83 (see Appendix 1.1.) is probably due to a diffusion front emanating from major fissures and permeating the unfissured "blocks" of marl. These bands are known as Liesegang rings and are seen as a subtle orangey discolouration of the brown marl. This diffusion appears to take place principally in a horizontal direction. The boundary between the grey marl and the brown marl is seen in few exposures. It appears to run parallel to the ground surface (as seen in road cuttings on the new Limassol road) and is a relatively sharp boundary with perhaps 1 to 2m of slightly mixed or mottled material. Fig. 3 shows a cut at the brown/grey boundary at Eylenja: fissures containing crystalline gypsum run along the boundary and connect with the predominant vertical fissure system above. Movement of ground water along these sub-horizontal fissures is clearly seen. The grey marl, even close to the boundary, appears to be massive with few fissures. All fissures appear to contain black manganese oxide staining but not all fissures are associated with the light grey clay. This clay is more plastic than the light grey, slightly sandy, thin laminations associated with the "veins".

5.2. Discontinuities

The reason for the presence of dominantly vertical fissuring in the brown marl is not wholly clear. As a clay approaches the ground, owing to erosion and associated uplift, the applied stress acting downwards decreases. This stress release allows the clay to expand under the influence of recoverable strain energy (Bjerrum, 1967) causing moisture to be drawn into the clay fabric (e.g. Skempton, 1961). Tensile failure during the shrinkage will produce vertical cracks sometimes to considerable depths. Also shear failure may be produced in a shrinking mass where the minor principal stress in the horizontal direction becomes negative, (Williams & Jennings, 1977). Alternatively, passive shear failure may occur due to erosion and a decrease of the vertical stress (Skempton, 1961). The small scale of the shear displacements found is inconclusive. The existence of previous shear displacements becomes significant when the shear strength along a discontinuity is vital to the stability of a foundation on a slope or a landslip. The amount of shear determines to what extent the shear strength has dropped to its residual value for that material (Skempton, 1974). The limited evidence in the Nicosia area for landslipping or cutting failure in the marls makes it difficult to ascertain the role of the discontinuities in any hypothetical stability problems.

An example of instability is found at the Ayios Nicolaos Clinic in the Lykavitos are a of Nicosia (G.R. 917340) where severe damage of a single storey structure includes lateral and diagonal shearing of columns and walls throughout the building. It appears that the spur of brown marl on which the hospital is sited has recently moved laterally by as much as 0.5m. The slope is steep (approx. 60°) but there is no evidence of landslip activity at the present time. It is possible, of course, that remedial measures, including a massive concrete retaining wall and drainage, have removed any evidence of slipping.

No sub-surface investigations have been made as far as the authors are aware. It is possible that the clinic was partially founded on fill material.

The Nicosia Formation has only been slightly folded. The study area is bisected by a wide syncline with axis running N75W (parallel to the Troodos margin) and about 1 km north of Kato Lakatamia and Laxia (Ducloz, 1964). Bedding on both sides of the syncline varies between 0° and 15° occasionally reaching 20°. Three main joint sets are found aligned approximately NNW, NNE and ENE, the two former being most prominent. Some faults of small displacement are associated with these joints. No evidence is found, however, of large scale faulting. Nevertheless, in the area around the Makharios Stadium (e.g. at Arkhangelos and Makedonitissa) severe small-scale folding and faulting is found (see Fig. 3) in heavily jointed brown marl. This is probably associated with the Ovgos fault zone to the north where the Nicosia marl is faulted against the Middle Miocene Kythrea Flysch. The folding, apparently in an EW direction and fold-induced micro-faulting extends from depth of 4.0m to an unknown depth. An upper band of havara is itself folded in places, as is the overlying calcarenitic marl with f.-m gravel lenses. The disturbance has led to intense fracturing and this combined with the thin bedding has resulted in incompetence and instability of even shallow cuts at least in dry conditions. Slickensiding is seen both on bedding and joint planes. All discontinuities are coated with calcium carbonate and manganese oxide.

5.3. Stress History

Laboratory results from consolidation and index tests point to the fact that the Nicosia marls are overconsolidated, but to what extent is not clear (see section 3.3.4.). Values for O.C.R. range from 3 to 16 (for 20 tests carried out at G.S.D.) with a mean of 8.6. Special high-pressure consolidation tests on samples from borehole EG 20/83 from a depth of 13.0m, carried out at B.G.S. produced O.C.R.'s of 24 and 11.00. The results from these tests (see Fig. 12) cast doubt on the adequacy of the stresses achieved by the conventional oedometer apparatus.

Liquidity indices, which are close to zero, support the conclusion of overconsolidation. The shear strength v depth profiles are not, however, conclusive; they do not exhibit the rapid increase of strength with depth demonstrated by some overconsolidated clays (see Lambe & Whitman, 1978). This is no doubt due to the non-homogeneity and variable cementation of the sediments. Similarly, S.P.T. v depth profiles are inconclusive with regard to stress history.

Geological evidence points to a period of emergence and erosion at the end of the Nicosia Formation deposition and prior to the deposition of the Athalassa and Kakkaristra Formations, but this period of erosion was probably brief (Ducloz, 1964); the depth of material eroded is not indicated. In recent times erosion has taken place quite rapidly, partly as a result of flash-flooding and partly as a result of man's influence in removing the vegetation cover (Everard, 1963).

6. CLASSIFICATION & ENGINEERING BEHAVIOUR

6.1. Classification Systems

A sample 'grouping' table is shown in Fig. 18. This is not intended as a classification but simply groups those samples tested from boreholes EG 7/82 to EG 18.82, according to their plasticity and lithology.
The first stage in dividing the 39 samples tested is by BSCS plasticity rating into four groups: EH; VH; H and I. Secondly, we have a colour/texture/stratigraphy description and finally simple swelling and carbonate content ratings of high, medium and low. It was found during preparation of the Geotechnical Map of Nicosia (Hobbs & Loucaides, 1982) that purely lithological descriptions of marls, made by a variety of people, were often unreliable guides to the geotechnical behaviour of the marls. For example, a sample described as a 'calcarenitic marl' may have a lower carbonate content, lower strength and higher plasticity than another described as 'marl'. This is not to say that the lithological description is wrong; indeed cementation for example is a difficult property to quantify, but that such a description may cover a wide range of geotechnical behaviour, which may overlap that of a different litholigcal group.

The British Soil Classification System (BSCS) for Engineering Purposes (ref: BS 5930, 1981 section 42.3; formerly C.P. 2001) has been utilized here in preference to the American Unified Soil Classification System (USCS - derived from the Casagrande Classification) because of its more detailed subdivision of the high plasticity clays. The BSCS subdivides the USCS group 'CH' into three groups: CH - high plasticity clay, CV - very high plasticity clay and CE - extremely high plasticity clay; the Liquid Limit ranges being CH-50 to 70, CV-70 to 90, CE-greater than 90.

Below the Casagrande A-line (see Fig. 5), the BSCS divisions are MH. MV and ME, equivalent to the clay divisions above. All Nicosia marl samples from boreholes EG 7/82 to EG 18/82 fall within groups CH, CV, CE, MV and ME except for EG 16, 5.0 (a calcarenitic marl) and EG 13, 2.0 (a re-worked soil) both of which are in group CI (intermediate plasticity clays). The BSCS has been used as the primary division of the Nicosia marls in the general sample grouping table shown in Fig. 18.

Fig. 18 SAMPLE GROUPING TABLE

B.S.C.S. PLAS. GROUP	Ei (TANG. MOD.)	SAMPLE DESCRIPTION	B.H. NO.	DEPTH (m)	SWELLING PRESSURE (KPa)	CARBONATE CONTENT
		CLAY	9	3.5 - 4.0	?	LOW
		V. DISTURBED LAMIN. KHAKI MARL	16	2.0 - 2.5	?	
	8,100		17	4.0 - 4.5		
EH	10,000		17	5.0 - 5.5		
		YELLOW/BROWN MARL WITH GREY	18	3.0 - 3.5	HIGH	MODERATE
		CLAY IN FISSURES	18	5.0 - 5.5		?
			18	7.5 - 8.0	*	?
	4,400	GREY MARL	7	11.0 - 11.5		
	16,000	REWORKED KHARKI MARL	7	2.0 - 2.5	LOW	
		REWORKED RUBBLY CLAY	9	2.0 - 2.5	*	
	20,000		17	3.0 - 3.5		LOW
			7	6.0 - 6.5	*	
	8,500		8	5.0 - 5.5	MODERATE	
VH			7	4.0 - 4.5	*	
		YELLOW/BROWN/KHAKI	14	7.5 - 8.0		
	14,000	MARL WITH GREY CLAY	14	9.5 10.0		
		IN FISSURES	15	3.0 - 3.5	* HIGH	VERY LOW
			14	2.0 - 2.5		
			18	4.0 - 4.5	*	
	6,500		18	9.5 - 10.0	*	MODERATE
	25,000		18	11.0 - 11.5		
	28,000	GREY MARL	14	11.0 - 11.5	* MODERATE	LOW
	5,000		7	13.0 - 13.5		
		REWORKED MARL ?	13	3.0 - 3.5	LOW	
		RED/BROWN MARL (APALOS?)	13	4.0 - 4.5	*	MODERATE
	22,000		14	3.0 - 3.5	* MODERATE	
	17,500	YELLOW/KHAKI MARL	14	6.0 - 6.5		
H	14,500		14	4.0 - 4.5	*	
			14	5.0 - 5.5		
	15,000		15	9.5 - 10.0	*	HIGH
	7,500	CALCARENITIC MARLS	16	6.0 - 6.5	LOW	
	30,000		16	4.0 - 4.5	*	MODERATE
			15	7.5 - 8.0	*	
			8	3.0 - 3.5		LOW
		YELLOW SANDY MARL WITH	8	2.0 - 2.5	* MODERATE	
		GREY CLAY IN FISSURES	8	4.0 - 4.5	LOW	
	17,500	YELLOW MARL WITH GREY CLAY IN FISSURES	17	6.0 - 6.5	MODERATE	MODERATE
I	25,000	REWORKED SOIL	13	2.0 - 2.5	* LOW	LOW
		MARLY CALCARENITE	16	5.0 - 5.5	LOW	VERY HIGH

BSCS GROUP	L.L.
EH	> 90
VH	70 → 90
H	50 → 70
I	35 → 50

SWELLING PRESSURE (KPa)	
LOW	< 20
MODERATE	20 → 35
HIGH	> 35

CARBONATE	%
VERY LOW	< 25
LOW	25 → 35
MODERATE	35 → 45
HIGH	45 → 55
VERY HIGH	> 55

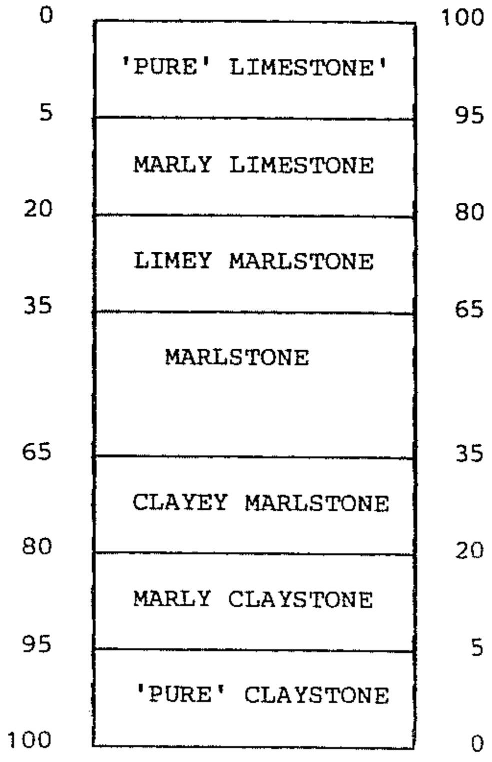
(* Estimates based on index and mineralogical data)

Fig. 18

Sub division of soils on the basis of grain size distribution is incorporated in both BSCS and USCS but only for the coarser materials. A petrological grain-size classification, based on a ternary clay/silt/sand diagram (Folk, 1974) is shown in Fig. 16. The marls are concentrated in a small triangle on the silt side of the 'mud' and 'sandy mud' units. Samples rich in carbonates tend to lie to the 'silt' or 'sand' side of the marl triangle. Samples (three in number) of grey marl lie to the silt side of the triangle.

The grading curves themselves (see App. 2.2.) show that the carbonate-rich marls tend to have medium to coarse silt as their main constituent. A plot of montmorillonite content v % clay (Fig. 17) shows that, in general, carbonate-rich marls have a low %montmorillonite/%clay ratio for %clay < 37. Thus it would appear that some part of the carbonate is clay-sized but the majority is silt-sized.

A simple classification for marls proposed by Fookes and Higginbottom (1975) is shown below:



If this is now incorporated in an empirical ternary diagram of clay/carbonate/quartz etc. (see Fig. 16) the basis of a marl classification is formed. The classification includes the sub-divisions marl (M), sandy marl (SM), calcarenitic marl (CM), marly calcarenite (MC) and Havara (H)*. Little data, other than that from boreholes EG 7/82 to EG 18.82 is available with both carbonate and clay fraction results. Thus further available with both carbonate and clay fraction results. Thus further data may dictate modifications, hopefully of a minor nature, to this ternary classification (see Fig. 16). Clearly carbonate content, clay fraction (and montmorillonite content) are key properties determining the behaviour of the marl.

6.2. Engineering Behaviour

6.2.1. General

The engineering behaviour of the Nicosia Marls is summarised in the table shown in Fig. 19. This is not intended as a basis for design calculations but simply as a summary of the geotechnical behaviour of the marl known to date and as a guide to the likely range of engineering behaviour. This table necessarily describes different types of marl in isolation and does not account for vertical successions of different marl types or marls with other rock types, such as calcarenites or gravels. In fact it is unusual to encounter a uniform marl (M) at shallow depth which does not contain lenses or bands of calcarenitic marl (CM) marly calcarenite (MC), calcarenite, havara (H)* or gravel. The marl (M) is however, the one component of such a mixed succession which is most susceptible to plastic deformation, swelling and shrinkage. The other problem in classifying shallow marl is the presence of highly variable 'reworked' material whose engineering behaviour may differ significantly from that of the underlying 'undisturbed' material. Marl naturally reworked by, for example, slope movement (colluvium) is, however, generally looser and more variable than the former. It has been found that shallow samples (3m depth) behave less predictably than deeper samples, due to the seasonal wetting and drying consequent breakdown of the fabric, and to the variable influence of farming, vegetation and topsoil genesis generally.

* A deposit of almost pure calcium carbonate, produced by the leaching process.

Fig. 19 TABLE OF LIKELY ENGINEERING BEHAVIOUR

MARL TYPE (based on classif. in fig. 16)	B.S.C.S. PLASTICITY CLASSIF.	CONSISTENCY/ STRENGTH CLASSIF. (C.P. 2004)	GRADING/ PERMEABILITY	SWELL/ * SHRINK POTENTIAL	COMPRESSIBILITY WHEN SATURATED	SHALLOW FOUNDATIONS	EXCAVATION/ FILL/CONCRETE ATTACK Etc.
MARL	EH	Firm to very stiff (or hard) depending on degree of cementation & overconsolidation; fresh marl may be up to 30% stronger than weathered marl.	Clay & fine silt/ poor drainage but modified by weathering/perm. is low.	High	Moderate at pressures up to 500 kPa. Low above 500.	Good foundation/ Bearing pressures <200 kPa should be founded at depth >4m/Excavations should be protected from moisture variation and supported if >4m deep.	Fresh marl may contain sufficient insoluble sulphates to cause concrete attack. Weathered marl is relatively free of insoluble sulphates but may contain pockets of gypsum/generally poor fill material partic. EH and VH.
	VH		AS ABOVE	Moderate to high	Low to moderate at pressures up to 200 kPa, Low above 200.		
	H		Med. to coarse silt/drainage is moder. poor/ perm. is low.	Low to moderate	Low		
SANDY MARL	H I	Soft to v.stiff 0 higher than for 'marl'. (SPT tends to be high)	Well-graded, Med. to coarse silt/ perm is low/ drainage is poor	Low to moderate	Probably low	Good foundation. May contain soft lenses or bands.	As for marl. Dry slopes may suffer progressive collapse. Moderately good fill material.
HAVERIZED MARL	H I	Soft to v.stiff depending on degree of cementation	F.Sand, silt and clay. Drainage moder.	Very low to low (?)	May be highly compressible	Unreliable foundtn. May be removed if thin layer.	May suffer soln. and leaching/poor fill material.
CALCARENITIC MARL	H	Firm to v. stiff.	Moder. well graded med.→coarse silt & f. sand. Permeab. is low. Drainage is poor.	Low	Moderate at pressures up to 500 kPa. Low above 500.	As for marl	As for marl/moderately good fill material.
MARLY CALCARENITE	I CL	Firm to v.stiff.	Moder. poorly graded. Fine sand, coarse silt. Permeab. is low. Drainage is poor.	Low	Variable with cementation. Probably low to very low.	V. good foundtn. but may contain voids or bands of softer marl.	Excavation may be difficult, esp. with bands of calcarenite present. Good fill material.
REWORKED MARL (incl. colluvium)	Variable	V. variable/generally firm. Possib. shear planes parallel to ground.	V. variable. May contain sands & gravels and voids. Drainage poor→moder. good.	Low	Variable. May be highly compr.	Poor foundation due to variability. May contain planes of weakness, partic. on slopes.	Excavation may result in instability partic. when wet.

* swell/shrink potential may be reduced by concentrations of iron salts and calcites

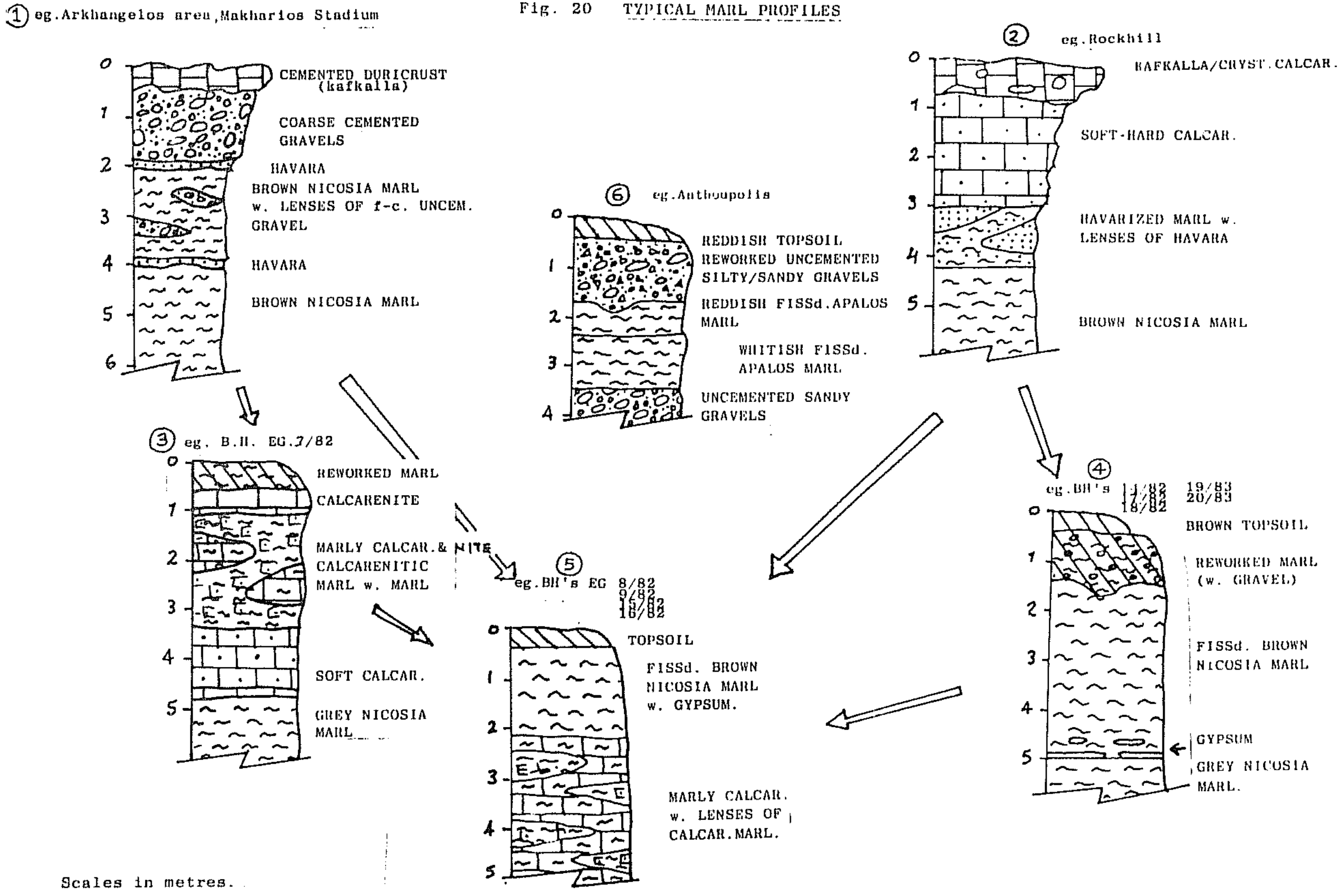
In borehole EG 19/83 an incompetent rubbly, reddish-coloured marly soil was encountered to a depth of 5.0m. This material was too loose and variable to sample and test successfully, but nevertheless represents a foundation hazard at this site.

Fig. 20 shows the range of shallow soil profiles involving marl encountered in the greater Nicosia are in simplified diagrammatic form. Six types of marl profile are identified (i.e. profiles with marl as a major component). Profiles 1 and 2 are found on hill-tops and profiles 3 and 4 are found at midslope and at valley-bottom. Examples from which the profiles were constructed are quoted in Fig. 20, as well as their equivalent profile or stratification code used for the Nicosia Geotechnical map (see Hobbs & Loucaides 1982). Bearing capacity analyses of stratified soils are confined to either approximate solutions for simple two layer purely cohesive cases or complex finite-element solutions for three or more layer cases where ideal elastic behaviour is assumed for each layer. (Poulos & David, 1974; Feda, 1978).

6.2.2. Bearing Capacity

Fig. 21.2 (a) shows the ideal homogeneous, or one layer case, Boussinesq pressure 'bulb' or iso-stress contour, (Fig. 21.2 (b)) such as might obtain in profile 4 (Fig. 20). Fig 21.2 (b) shows the pressure bulb for an upper layer half the foundation diameter in thickness and with a Youngs Modulus of Elasticity ten times that of the underlying soil, as for example in profiles 1, 2, and 3 in Fig. 20. These layers are then reversed in Fig. 21.2 (c) as for example in profiles 5 or 6 in Fig. 20. From the diagrams it can be seen that in case (b) (Fig. 21.2), the stress in the lower layer is reduced significantly compared to case (a) (Perloff & Baron, 1976), but the area over which this reduced stress acts is greater (Leonards, 1962). conversely in case (c) (Fig. 21.2) the stress in the lower layer in increased compared to case (a). If the thickness of the upper layer is greater than approximately five times the radius of the foundation, the stress taken by the lower may be considered neglible whatever the value of E_1/E_2. If, however, the thickness of the upper layer is less than approximately half the foundation radius and the E_1/E_2 ratio is high (for example a thin duricrust on marl) nearly all the stress is taken by the weaker lower layer and the crust may fail by punching through

Fig. 20 TYPICAL MARL PROFILES



Scales in metres.

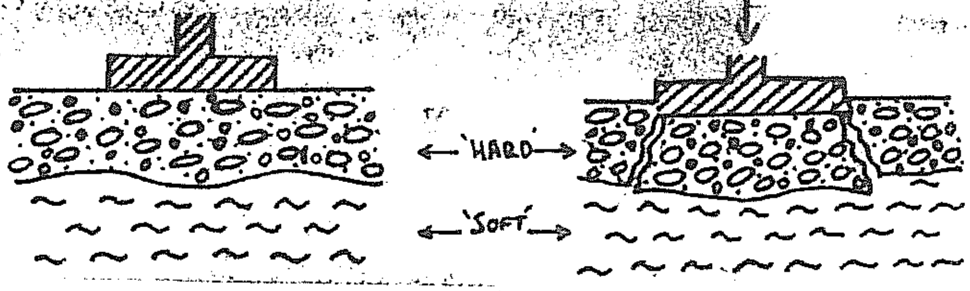


Fig. 21.1 PUNCH-THROUGH FAILURE

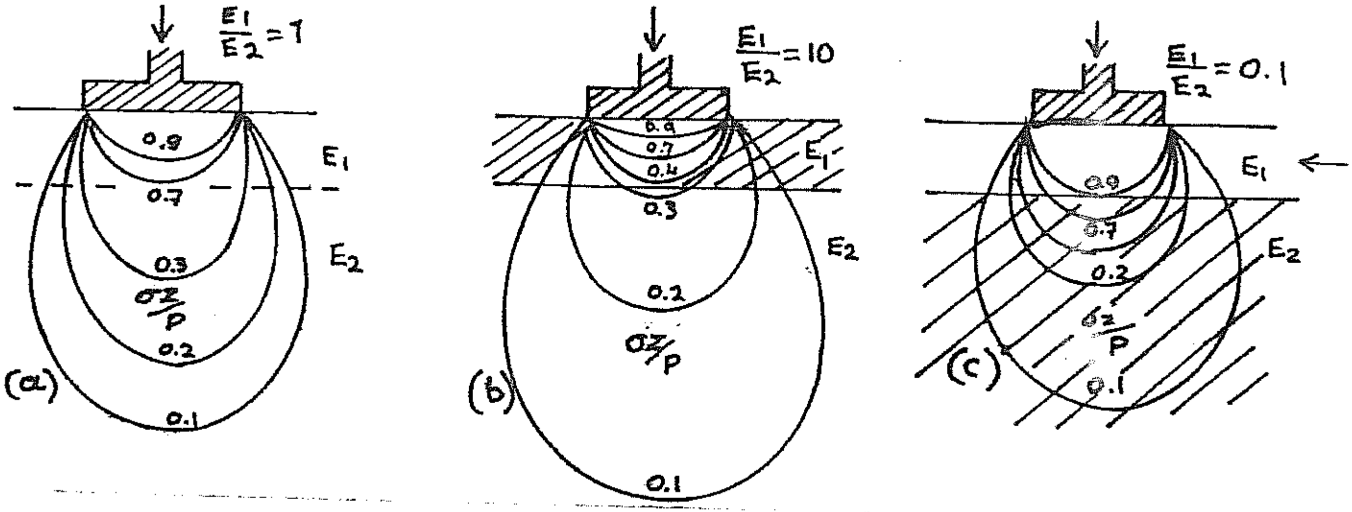


Fig. 21.2 BEARING PRESSURE CONTOURS BELOW A CIRCULAR FOUNDATION IN A 2-LAYER DEPOSIT (Ref:Poulos & David, 1974)

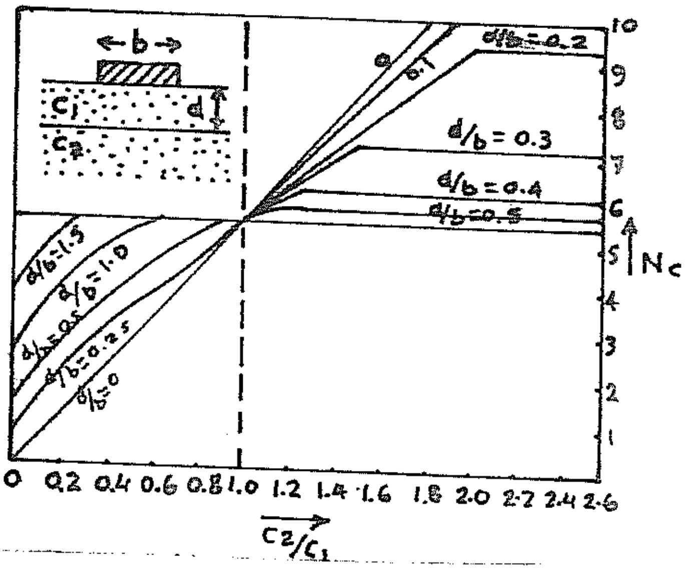


Fig. 21.3 BEARING CAPACITY FACTOR, Nc, FOR A 2-LAYER COHESIVE DEPOSIT (Ref: Button, 1953)

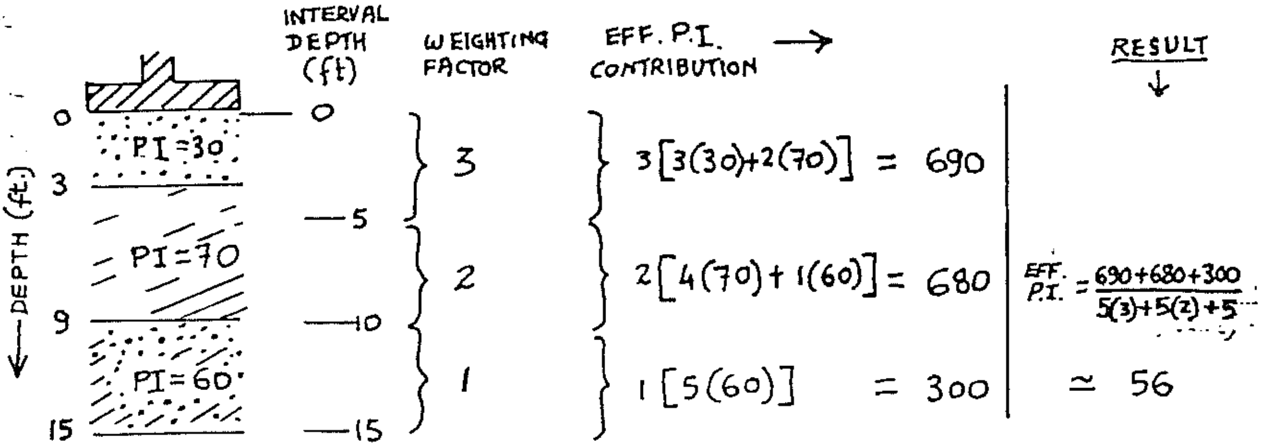


Fig. 22.1 EXPANSIVE POTENTIAL - EXAMPLE (B.R.A.B., 1968)

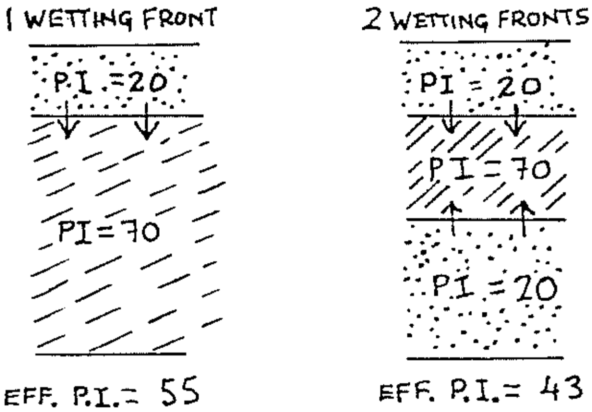
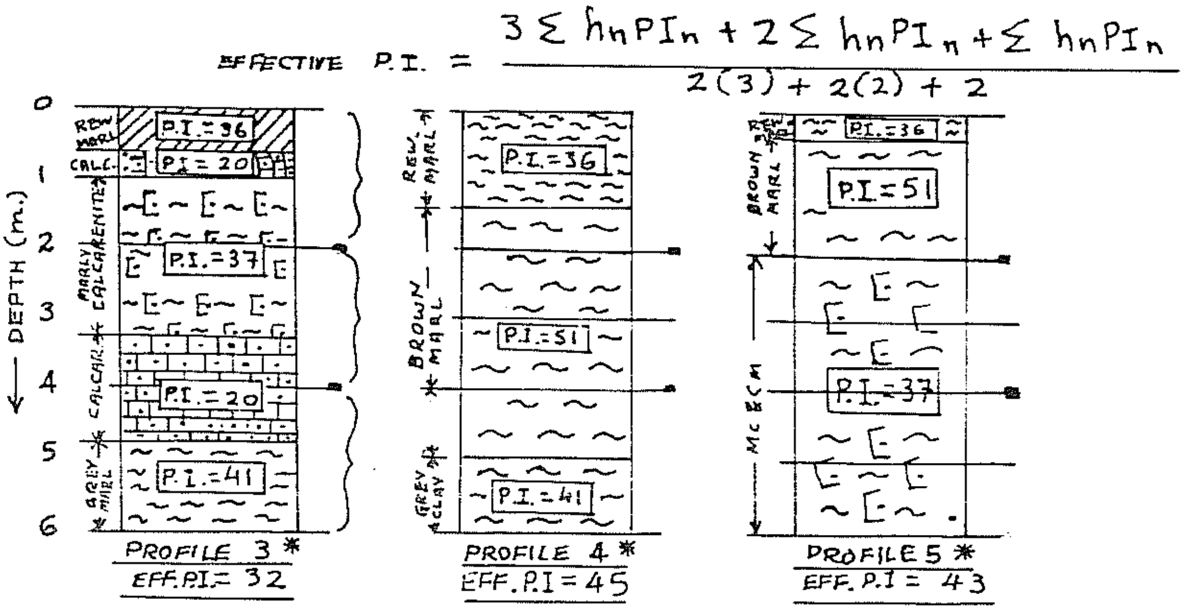


Fig. 22.2 EXPANSIVE POTENTIAL - EXAMPLE (Mathewson and Dobson, 1982)



$$\text{EFFECTIVE P.I.} = \frac{3\sum h_nPI_n + 2\sum h_nPI_n + \sum h_nPI_n}{2(3)+2(2)+2}$$

* Profile Nos refer to Fig.20

Fig. 22.3 EXPANSIVE POTENTIAL - NICOSIA MARL

Fig. 22 EXPANSIVE POTENTIAL OF SOIL PROFILES

Laxia (G.R. 867341). This process may be accelerated by shallow mining within or immediately below the duricrust, for example at Eylenja (G.R. 902365). The hazard to buildings on the duricrust close to its edge is obvious. Thick deposits of calcarenite often contain bands of weaker, fissured marl, which, if subject to rapid erosion, may reduce the competence of the rock mass as a whole.

Evidence for instability of man-made cuts in marl is confined to two types: firstly, gradual cutting-back of dry vertical slopes in fissured marl (particularly Apalos marl) is seen to occur as a result of fissures and shrinkage cracks which reduces the exposed marl mass to what is effectively a coarse granular material which fails retrogressively building up a scree at its foot (see fig. 3). Secondly, surface run-off during heavy rain may be channelled down open joints and fissures which emerge in a cut face; the water scouring fine or loose material from around the discontinuity to result in isolation and finally slump or toppling failure of what has become a free-standing block of marl. This is prevalent in built-up areas where drains cannot cope with the sudden flow of surface water, the effect of which is magnified by channelling along ditches, culverts, tarmac etc., and is noticeable within the uppermost reworked or colluvial marl and fill. A failure of this latter type was observed by the authors during heavy rain in the walls of a 6m deep basement excavation near the site of borehole EG20/82.

6.2.5. Compaction

Little information on the compaction of Nicosia marls is available for the authors at present. However, Anon, (1972) include five modified Proctor tests in their report on the Makarios stadium site investigation. The tests were carried out on admixtures of marl and sand obtained from trial pits throughout the pits depth. The coarser and less plastic admixtures gave notably higher maximum dry unit weights (1.90 g/cm^3) and lower optimum moisture contents (14%) than the finer grained, more plastic admixtures which gave γd = 1.70 g/cm^3 and m = 20%. The most favourable results came from a sample with a gravel content of 40%. Marl which is not mixed with coarse material may be expected to give a maximum dry density in the range 1.4. to 1.6 g/cm^3; i.e. generally poor for most purposes.

CONCLUSIONS

A wide range of geotechnical, mineralogical and geotechnical tests have been applied to marls from the Nicosia area. The results, which have been analysed and cross-correlated in some detail, show that the marl is a strong, plastic, carbonate-rich montmorillonitic, cemented and over-consolidated silty clay of moderate compressibility. A summary of the engineering behaviour of the various subdivisions of the marl is given in Fig. 19. The behaviour of the marl is closely related to moisture content, carbonate content, cementing, clay fraction and montmorillonite content, all of which are variable with both location and depth. The relative proportions of carbonate and montmorillonite are a key factor, as is the contribution of the carbonate content to cementing and hence possibly high strength-sensitivity. The particle-size grading of the marl is dependent upon the state of weathering and the carbonate content. More important, however, may be the particle-shape. It has been indicated (Ducloz, 1964) that a high proportion of non-clay mineral grains are angular as a result of very rapid erosion and deposition. This fact alone may have an important influence on the geotechnical properties including Atterburg limits and the strength. In fact the relatively high residual strength obtained may be a direct result of the angular nature of the silt fraction. A further consideration is the likelihood of aggregations of clay size particles into silt-sized 'peds', and their effect on the geotechnical properties. Detailed study of the test samples using a scanning electron microscope may prove to be most valuable in this respect.

Mineralogically there is little variation within the samples tested and a common origin is almost certain. Chemical tests did reveal, however, high total sulphate levels within the 'grey' marl samples, though only three were tested. The depth of the 'active zone', i.e. the depth to which seasonal water content variation takes place, is an important consideration. This may vary 3 m to 8 m depending on location and lithology. The discontinuity regime and hence the mass properties of the active zone material differs from that of the marl below. S.P.T. values are usually higher within the active zone for most of the year probably as a result of the cementation. A good relationship has been established between moisture content and log swelling pressure (see Fig. 15); a moisture content drop from 40% to 30% causing a tenfold increase in swelling pressure. This explains the damage due to heave experienced with many shallow (i.e. within the active zone) lightly-loaded foundations. Protection of the excavation, both before and after construction, from water content variation is thus seen to be critical. An attempt has been made to classify the marls according to carbonate and clay fraction (see Fig. 16). This appears to be a useful method but may require modification of the areas designated for calcarenitic marl and marly calcarenite, in the light of further testing. The problem encountered when describing or attempting to subdivide the marl is that marl and calcarenite are not mutually exclusive materials, but a smooth and uninterrupted grading from one to another exists with carbonate replacing clay mineral and vice versa. This grading from one to the other may occur laterally and vertically but is not always present. Sharp litholigical and geotechnical boundaries do exist but the materials either side of that boundary may lie anywhere along the marl — calcarenite scale. In fact the clay — carbonate scale is a two leg scale: one being clay — havara (i.e. pure fine-grained carbonate) and the other being clay — calcarenite (i.e. an impure coarse-grained carbonate). Thus a 'havarized marl' may differ from a 'calcarenitic marl' in terms of particle size grading and cementation, though having the same carbonate content. A successful measure of the degree of cementation has not been identified, but sensitivity may be an indirect indicator of cementation.

It is proposed that further studies of the marl include analysis of the microstructure to answer the questions of aggregation and cementation, and thus relate this to the geotechnical behaviour. Other fruitful area of the study include high pressure consolidation tests and ring-shear tests, both of which have produced interesting results which may prove characteristic of the marls. Finally it would clearly be a great advantage to be able to monitor the performance of a building and compare it with the theoretical behaviour obtained from the laboratory results. Alternatively, a test site may be found where seasonal moisture variation and volume change could be monitored at various depths within the active zone profile, along with small scale site loading tests.

BIBLIOGRAPHY

ANON (1972)

Report on site investigation at Makarios Stadium, Nicosia.
Messrs. Kotzias & Stamatopoulos, Athens, Greece.

ANON (1963)

Report on site investigation at Larnaca Road, Nicosia for Messrs. Raglan Squires & Partners, by the Cementation Co. Rep. No. 3629/MD M^cQ.

BARDEN L. (1972)

"The relation of soil structure to the engineering geology of clay soil".
Q.J.E.G. London, 5, pp. 85 - 102.

BAROZ & BIZON (1974)

"Le neogene de la chaine du Pentadaktylos et de la partie nord de la Mesaoria (chypre)".
Rev. de l'Ins. France du Petrol., Paris Mai-Juin, 1974 Vol. XXIX No. 3.

BEAR L.M. (1960)

"The Geology and Mineral Resources of the Akaki-Lythrodonda Area"
Geol. Mem. Geol. Surv., Cyprus, No. 3.

BJERRUM L. (1967)

"Mechanism of progressive failure in slopes of overconsolidated plastic clays and clay-shales".
J. Soil Mech - and Found. Div., A.S.C.E. Vol 93, pp 1 -49.

BUNTING B.T. (1965)

"The geography of soil".
Hutchinson University Library Publ.

BURLAND J.B., BROMMS B.B., de MELLO V.F.B. (1977)

"Behaviour of foundations and structures - State of the Art Report".
Proc. 9th Int. Conf. S.M.F.E., Tokyo, 2, pp. 495 - 546

BUTTON S.J. (1953)

"The Bearing Capacity of footings on a two-layer cohesive subsoil".
Proc. 3rd Int. Conf. on S.M.F.E., Zurich, Vol 1, p. 332.

CHANDLER R.J. (1969)

"The effect of weathering on the shear strength properties of Keuper marl".
Geotechnique 19, No. 3 pp. 321 -334.

CHAPMAN R.W. (1974)

"Calcareous duricrust in Al Hasa, Saudi Arabia".
Geol. Soc. Am. Bull., V. 85, pp. 119 -130.

CLEINTUAR M.R., KNOX G.J & EALEY P.J. (1977)

"The Geology of Cyprus and its place in the East-Mediterranean framework".
Geologie en Mijnbouw. Vol. 56 (1) pp. 66-82.

DAVIS A.G. (1967)

"The minerology and phase equilibrium of Keuper Marl".
Q.J.E.G., 1, No.1, pp. 25-38.

DEMARS K.R. & CHANEY R.C (1982)

Geotechnical Properties Behaviour and Performance of Calcareous Soils".
ASTM Spec. Publ. No. 777.

DUCLOZ C.E. (1964)

"Revision of the Pliocene and Quaternary Stratigraphy of the Central Mesaoria".
Geol. Mem. Geol. Surv., Cyprus, No. 8

EROL O.A. & DHOWIAN A.W. (1982)

"Swell and shrinkage behaviour of Medinah Active Clays".
J. Eng. Sci. King Saud Univ. Vol 8 (2) pp. 79-84

EVERARD C.E. (1963)

"Contrasts in the form and evolution of hill-side slopes in Central Cyprus".

Inst. Brit. Geogr. Trans., 32, pp. 31-47

FARRAR D.M. & COLEMAN J.D.

"The correlation of Surface Area with other properties of nineteen British clay soils".

J. Soil. Sci. 18, 1967.

FEDA J. (1978)

"Stress in subsoil and methods of final settlement calculation".

Developments in Geotechnical Engineering, Vol 18.

Elsevier Publ.

FOLK R.L. (1974)

"Petrology of Sedimentary rocks".

Hemphill Publ. Co., Texas, 182p

FOOKES P.G. & HIGGINBOTTOM I.E. (1975)

"The classification and description of near-shore carbonate sediments for engineering purposes".

Geotechnique, vol. 25, No. 2 pp 406-411

GASS I.G. (1960)

"The Geology and Mineral Resources of the Dhali area".

Geol. mem. Geol. Surv., Cyprus, No. 4

GAUDRY A. (1862)

"Geologie de l'Ile de Chypre"

Mem. Soc. Geol. France, Ser.2. VII.

GEORGIOU E. & MORGAN D.J. (1979)

"Investigation of Cyprus clay deposits as raw material for structural ceramics - Part 1: geology and mineralogical composition".

Mineralogy Unit, B.G.S. Rep. No. 239

GIBBS H.W. & HOLTZ W.G. (1957)

"Research on determining the density of sands by spoon penetration testing".

Proc. 4th Int. conf. S.M.F.E., London, 1957 Vol.1 pp. 35 - 39

GREY G.R., DARLEY H.C.H., ROGERS W.F. (1980)

"Composition and properties of oil-well drilling fluids".

Gulf. Publ. Co.

HARDY R.M. (1965)

"Identification and performance of swelling soil types".

Canadian Geotechnical Journal, Vol. 11, No. 2, 1965

HENSON F.R.S., BROWNE R.V. & McGINTY J. (1949)

"A Synopsis of the Stratigraphy and Geological history of Cyprus".

Q.J. Geol. Soc. London. 106, pp. 1 - 41.

HOBBS P. & LOUCAIDES G. (1982)

"The Geotechnical map of Nicosia".

G.S.D./B.G.S. Report, April 1982

HOBBS P., HORSEMAN S.T., McEWEN T.J. & YEOW H.Y. (1982)

"Swelling behaviour of Harwell mudrocks"

B.G.S. Report No. E.N.P.U. 82/11

HOLTZ W.G. & GIBBS H.J. (1956)

"Engineering properties of expansive clays"

Trans. A.S.C.E., Vol 121, p. 516

HORSEMAN S.T, HOBBS P., McEWEN T.J., AVERY L., FORSTER A. (1982)

"Basic Geotechnical properties of core from the Harwell boreholes"

B.G.S. Report No. E.N.P.U. 82/7, July 1982

HOUGH B.K. (1957)

"Basic soil engineering"

Ronald Press Co., New York, (2nd ed. 1969)

KATZIR M & DAVID D. (1969)
"Foundations in expansive marl"
2nd Int. Conf. on Expansive Soils Texas A & M Univ. Press 1969

KOMORNIK A. & DAVID D. (1969)
"Prediction of swelling pressure of clays"
journal of the Soil Mech. & Foundtns. Div A.S.C.E, Jan. 1969

KOMORNIK A., LIVNEH M. & SMUCHA S. (1980)
"Shear strength and swelling of clays under suction"
Proc. 4th Int. Conf. on Expansive soils Vol 2, pp. 206 - 226, publ. A.S.C.E. 1980

KOMORNIK A., ROHRLICH V. & WISEMAN G. (1969)
"Overconsolidation by desiccation of coastal late-Quaternary clays in Israel"
Sedimentology, 14, 1970 pp. 125 - 140

LADD C.C. (1964)
"Stress-strain modulus of clay from undrained Triaxial Tests"
Proc. A.S.C.E, Vol 90 No. SM5, Sept, 1964

LAMBE T.W. (1960)
"The character and identification of expansive soils"
Washington D.C. Federal Housing Admin. Tech. Publ. 701

LAMBE & WHITMAN (1979)
"Soil Mechanics"
Published Wiley International

LEONARDS G.A. (ed.) (1962)
"Foundation Engineering"
Publ. McGraw-Hill, Intern. Student edition

LUPINI J.F., SKINNER A.E., VAUGHAN P.R. (1981)
"The drained residual strength of cohesive soils"
Geotechnique, 31, No. 2, p. 181 - 213

MARSLAND A. (1973)
"Large in-situ tests to measure the properties of stiff fissured clays"
B.R.E. report CP 1/73

MATHEWSON C.C. & DOBSON B.M. (1982)
"The influence of geology on the expansive potential of soil profiles"
Geol. Soc. of Amer. Bull., V93, pp 565 - 571 July 1982

MESRI G., ULLRICH G.R. & CHOI Y.K. (1978)
"The rate of swelling of overconsolidated clays subjected to unloading"
Geotechnique 28, No.3, pp. 281 - 307, 1978

MOLNIA B.F. (1974)
"A rapid and accurate method for the analysis of calcium carbonate in small samples"
Journ. Sedim. Petrology. Vol. 44, No.2, pp. 598 - 590

NISHIDA Y. (1956)
"A brief note on compression Index of soil"
Journ of Soil Mech & Foundtn. Eng. Div. A.S.C.E.
Vol 82, No. SM3, Proc. Paper 1027, July 1956
pp. 1027 - 1 to 1027 - 14

PECK HANSON & THORBURN (1974)
"Foundation Engineering"
publ. John Wiley & Sons, New York, 2nd Ed.

PENMAN A.D.M. & GODWIN E.W. (1975)
"Settlement of buildings and Associated Damage"
B.R.E. Current Paper 33/75

PERLOFF W.H. & BARON W. (1976)
"Soil Mechanics Principles and Applications"
Publ. Ronald, New York.

POULOS H.G. & DAVID E.H. (1974)
"Elastic Solutions for soil and Rock Mechanics"
Publ J. Wiley & Sons, New York

PUSCH R. (1980)
"Swelling pressure of highly compacted bentonite"
SKBE/KBS Teknisk Rapport 80 - 13, 1980

REED F.R.C. (1930)
"Contributions to the Geology of Cyprus (Part II): The Tertiary Formations"
Geol. Mag. LVX II

REED F.R.C. (1935)
"Notes on the Neogene faunas of Cyprus, III: The Pliocene Faunas"
Ann. Mag. Nat. Hist. Ser. 10 Vol XVI

RENDEN HERRERO O. (1980)
"Universal compression index equation"
Journ. Geotech Eng. Div A.S.C.E. No. GT 11 Nov. 1980
pp. 1179 - 1200

ROBERTSON A.H.F. (1977)
"Tertiary uplift history of the Troodos Massif, Cyprus"
Geol. Soc. of Amer Bull v88 1763 - 1772

RUSSELL R. (1882)
"On the Geology of the Island of Cyprus"
Q.J. Geol. Soc. London, 105, pp. 1 - 41

SARNTHEIN M & WALGER E. (1973)
"Classification of modern marl sediments in the Persian Gulf by factor analysis"
The Persian Gulf, pp. 81 - 98, Springer Verlag, Berlin

SAUNDERS M.K. & FOOKES P.G. (1970)
"A review of the relationship of Rock Weathering and climate and its significance to Foundation Engineering"

SCHMERTMANN J.H. (1969)
"Swell Sensitivity"
Technical Note, Geotechnique, 19, pp. 530 - 533

SCHMERTMANN J.H. (1953)
"Estimating the true consolidation behaviour of clay from laboratory test results"
Proc. A.S.C.E. 79, seperate 311, 26 pp.

SCHMIDT S. 81963)
"Untersuchungen uber das Pliozan der Insel Cypern I-Ein wurmrohren (Serpuliden) - Bryozoenriff - Horizont, Sudlich, Leucossia (Nicosia, Cyprus)"
Ann. Geol. Pays Helleniques 14

SEED H.B., WOODWARD R.J. & LUNDGREN R. (1962)
"Prediction of swelling potential for compacted clays"
A.S.C.E. J. soil. mech., 88, No. SM3, pp. 53 - 87

SKEMPTON A.W. (1961)
"Horizontal stresses in an overconsolidated Eocene clay"
Proc. 5th, Int. Conf. soil. mech. Paris, 1, pp. 351 - 58

SKEMPTON A.W. (1964)
"Long term stability of clay slopes"
Geotechnique, 14, pp. 77 - 101

SPANGLER M.G. & HANDY R.L. (1982)
"Soil Engineering"
4th Ed. Publ. Harper & Row, New York

SRIDHARAN A. & ALLAM M.M. (1982)
"Volume change behaviour of desiccated soils"
A.S.C.E. J. Soil Mech. GT8 Aug. 1982

STAMATOPOULOS A.C. & KOTZIAS P.C. (1978)
"Soil compressibility as measured in the oedometer"
Geotechnique, Vol. 28, pp 363 - 375

TERZAGHI K. & PECK R.B. (1967)
"Soil Mechanics in engineering practice"
2nd Ed. J. Wiley & Sons. Wiley Intern. Ed. New York

WARKENTIN B.P. & BOZOZUK M. (1961)
"Shrinking and swelling properties of two Canadian clays"
Proc. I.C.S.M.F.E., 5th Paris, 3A, p.851

WILLIAMS & JENNINGS (1977)
"The in-situ behaviour of fissured soils"
Proc. I.C.S.M.F.E., 9th, Vol. 2, Tokyo

YONG R.N. & WARKENTIN B.P. (1975)
"Soil properties and behaviour"
Elsevier Publ. Amsterdam.

B.S. 1377 (1975)
"Methods of testing for soils for engineering purposes"
British Standards Institute publ., April 1975

BUILDING RESEARCH ADVISORY BOARD (1968)
"Criteria for selection and design of residential slabs-on-ground"
Federal Housing Admin. Report No. 33

C.P. 2004 (1972)
"Code of practice for foundations"
British Standards Institute publ. Sept. 1972

Report of the sub-committee on Standardisation of penetration Testing in Europe.

Proc. 9th I.C.S.M.F.E., Vol. 3, 1977, Tokyo (App.5)

PHOTOGRAPHIC LOG OF

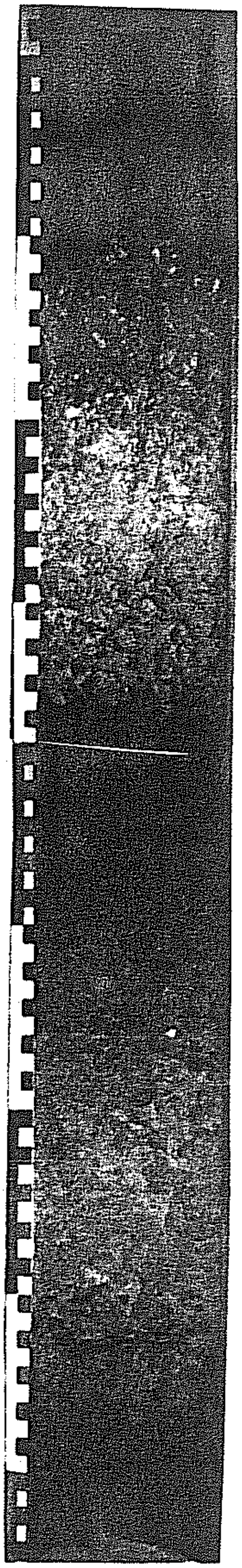
B.H. EG 20/83

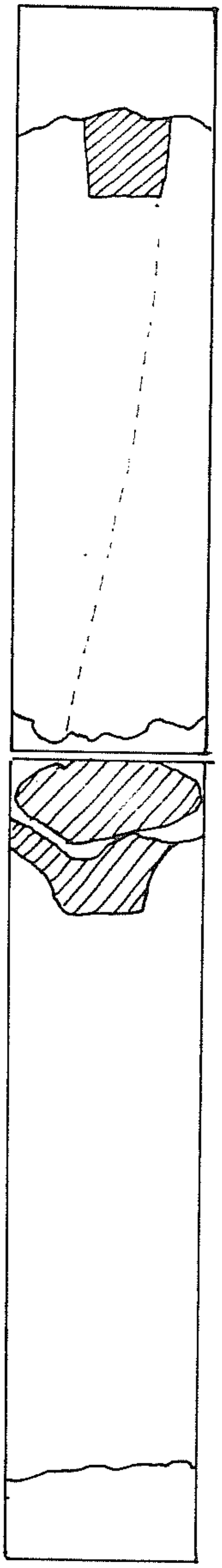
KEY:

⬭	PRIMARY VEINING (GREY COLOURED)
⬬	SECONDARY VEINING (USUALLY DARKER GREY)
◌	CONCENTRATION OF IRON OXIDE
••••	MANGANESE OXIDE (STAINING USUALLY IN JOINT OR FISSURE)
— —	FISSURE, JOINT OR SEPARATED BEDDING PLANE
〰	BANDING (DUE TO DIFFUSION)
⌒	SHELL, FOSSIL
▨	MATERIAL DISTURBED BY DRILLING OPERATIONS

N.B. Colour codes referred to are taken from the Munsell Soil Colour Chart (see Ref. list) e.g. 2.5Y5/6 indicates a yellowish 'hue' (2.5Y), a 'value' (darkness) of 5 on a scale of 1 → 10, and a 'chroma' (strength) of 6 on a scale of 1 → 8.

2.5Y5/4	light olive brown
2.5Y5/6	" " "
2.5Y6/4	light yellowish brown
5Y6/2	light olive grey
5Y5/1	grey
10YR6/8	brownish yellow



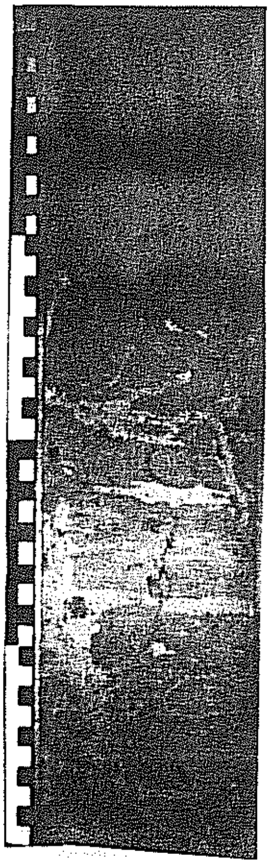


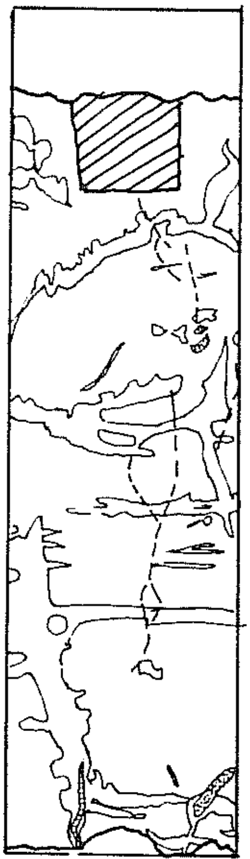
Depth: 1.0 - 1.5 m

Dry, friable, highly fiss$^{\underline{d}}$., 2.5 Y 6/4 clayey silt (reworked MARL) with some med. gravel and sand (igneous). A few pockets of carbonate. Some slickensiding on 45^{o} fissures. Traces of manganese staining on fissures. Hcl reaction.

Depth: 1.5 - 2.0 m

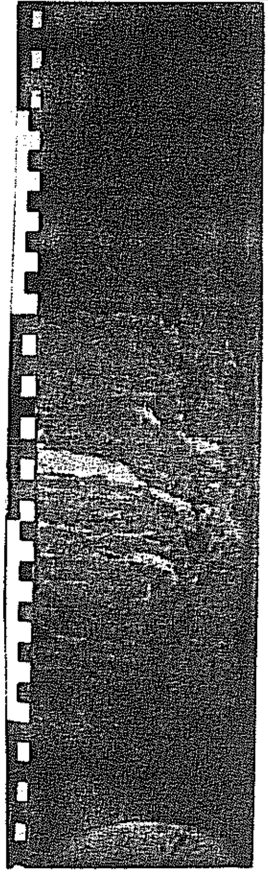
Alternating bands of slightly fossiliferous mottled 2.5 Y 6/4 and 5 Y 6/2 f. sandy silt (sandy MARL); probably reworked. Sandy marl is friable, open and structureless whereas marl is highly fissured. Small borings or rootlets throughout some pockets of carbonate and little f-m gravel (igneous). Hcl reaction.

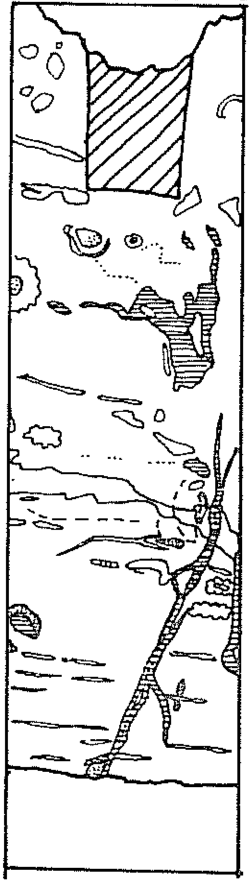




Depth: 2.0 - 2.5 m

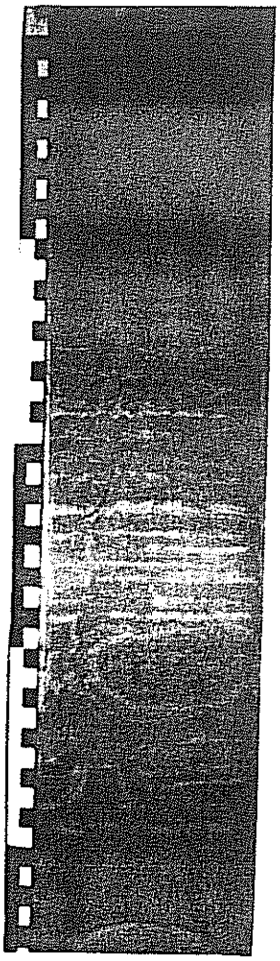
Hard, fissured, 2.5 Y 5/6 clayey silt (MARL) with pronounced veining of softer 5 Y 6/2 clayey silt and silty clay (MARL) associated with sub-vertical and also sub-horizontal fissuring with some slickensiding. Horiz. veins tend to be slightly sandier. Laminations of f. sandy silt in both materials. Strong dendritic manganese staining in fissures. Hcl reaction throughout. A 'secondary' darker coloured veining visible at base.

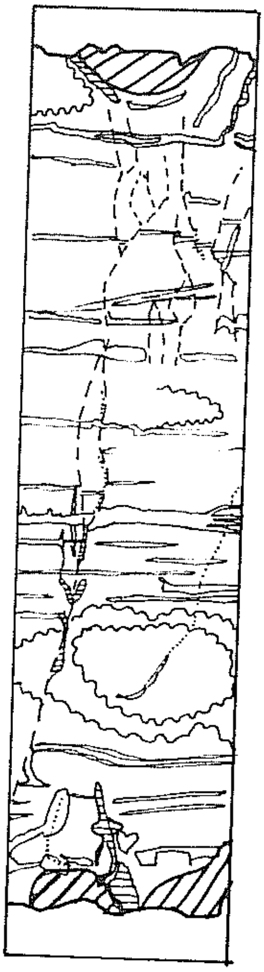




Depth: 2.5 - 3.0 m

As above; main vein is noticeably plastic soft clay. At centre of horiz. veins is a very thin lamination of very fine sand or coarse silt associated with heavy manganese staining. Heavy fissuring and slickensiding predominates near main sub-vert. vein. 'Secondary' darker veining cuts through primary vein. Hcl reaction throughout.

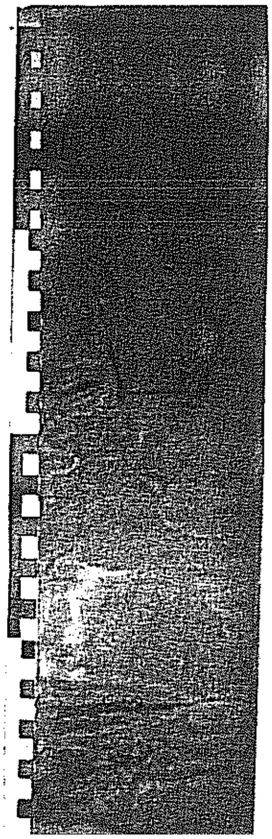


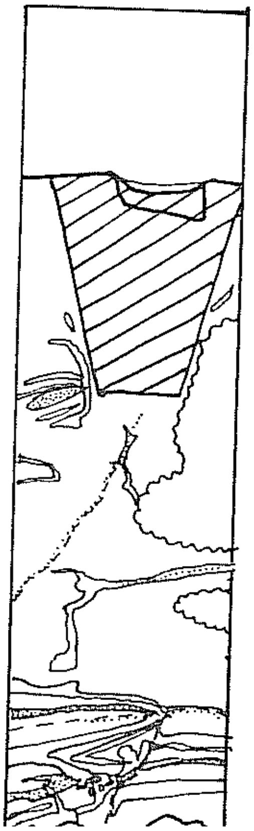


Depth: 3.5 - 4.0 m

Horizontally laminated hard, fissured silty clay and clayey silt (MARL) 2.5 Y 5/6 with laminations and veins of 5 Y 6/2. Sub. vert. fissures have slickensiding and manganese staining; shear displacements of a few mm's. Some coinchoidal fracturing in 2.5 Y 5/6 marl and circular banding (i.e. discoloration) probably due to percolation through marl mass. Horiz. laminations are coarser than bulk. Hcl reaction throughout.

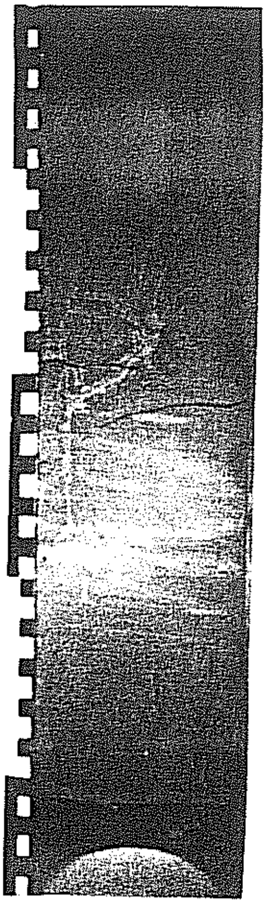
Note: drilling disturbance is negligible.

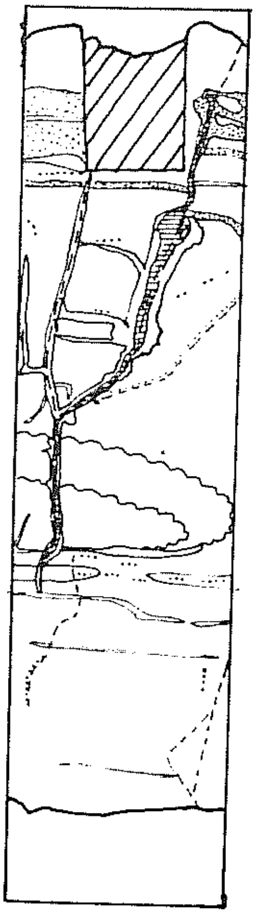




Depth: 4.5 - 5.0 m

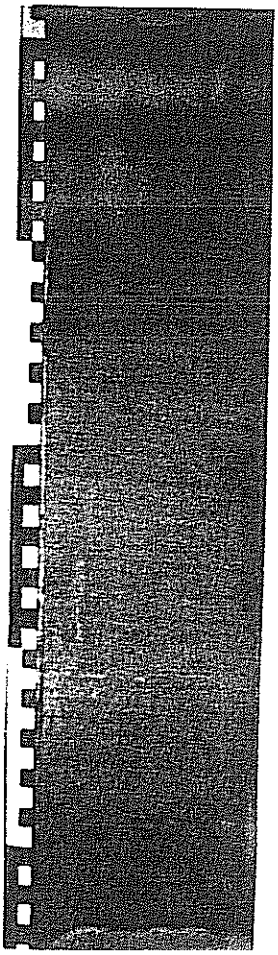
MARL as above, but few horiz. laminations and more prominent circular banding. Fissuring and veining is much reduced. Fissures are closed and coated with a very thin smear of light coloured clay, manganese staining, and at the base iron oxide. Fine laminations contain thin sandier material. Slickensiding on sub. vert. fissures. Hcl reaction.

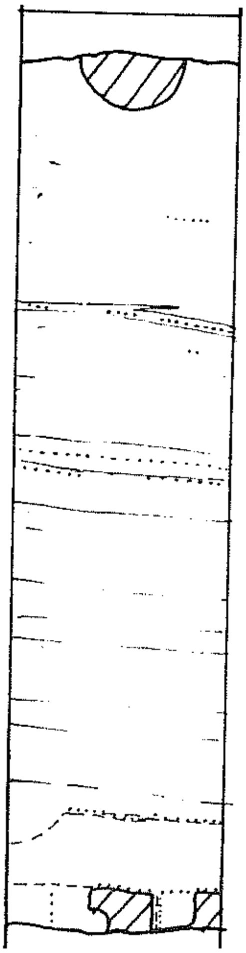




Depth: 5.5 - 6.0 m

Firm-hard laminated silty clay and clayey silt (MARL) 2.5 Y 5/4 with veins of 5 Y 6/2 (primary) and 5 Y 5/1 (secondary). Major sub. vert. vein cuts horiz. laminations and circular banding (centre). Small shear displacement on fissures. Manganese staining on most fissures. Veins interconnected horizontally. Hcl reaction throughout.

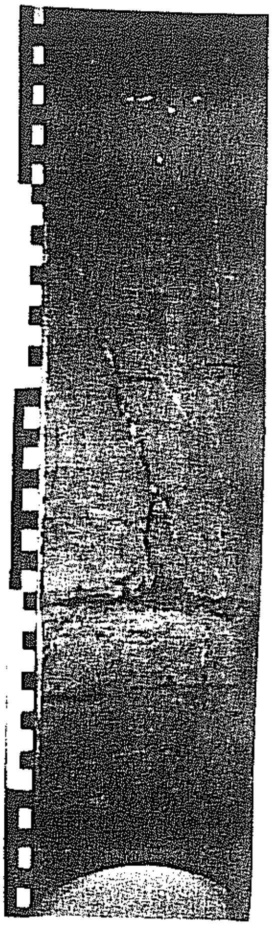


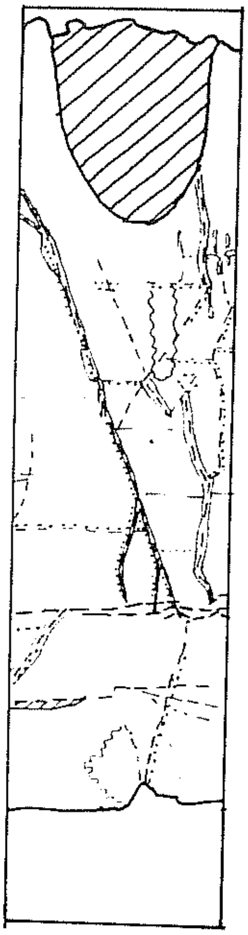


Depth: 6.5 - 7.0 m

Hard, laminated, uniform. No fissures except at base. No veining except for horiz. laminations. Manganese staining on some open laminations. Material generally finer and more competent than above. Little drilling disturbance. Hcl reaction throughout.

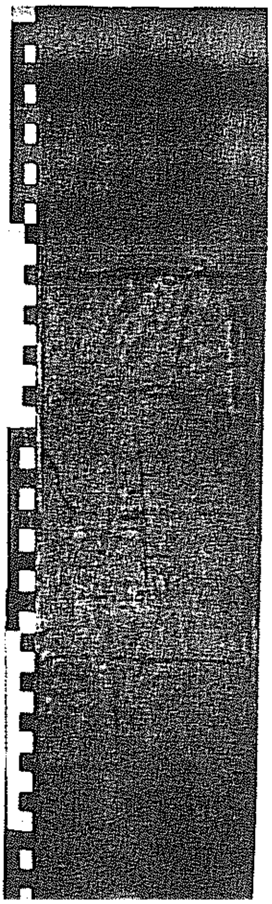
Note: vert. fissure at base terminated by horiz. lamination.

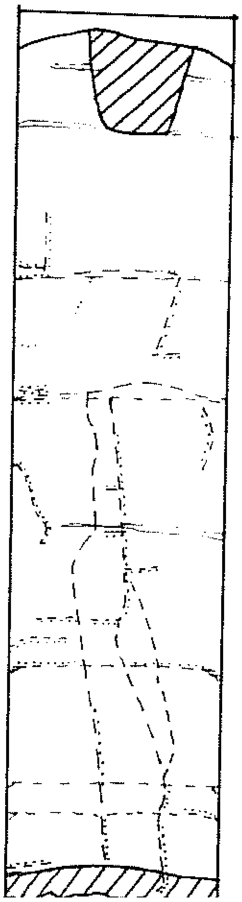




Depth: 7.5 - 8.0 m

Strongly fissured, hard, laminated 2.5 Y 5/6 silty clay and clayey silt (MARL). Interconnected sub. vert. veins contain soft 5 Y 6/2 clay and manganese staining. Shear displacements vary from 2 to 10 mm. Some closed fissures contain no 5 Y 6/2 clay only manganese staining. Some disturbance at open horiz. fissures (lower half) where coarser material has possibly been lost. Slickensiding is seen in both 2.5 Y 5/6 and 5 Y 6/2 material. Hcl reaction throughout.

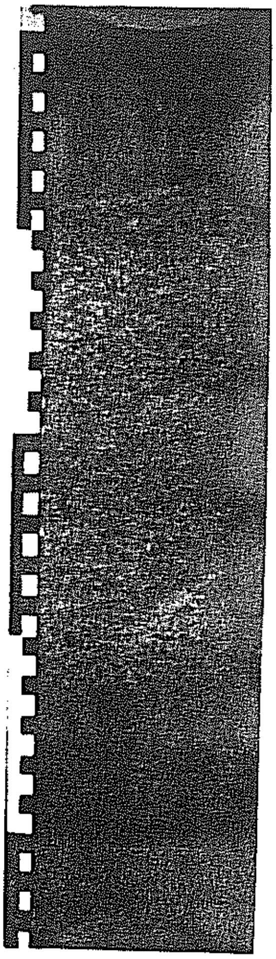


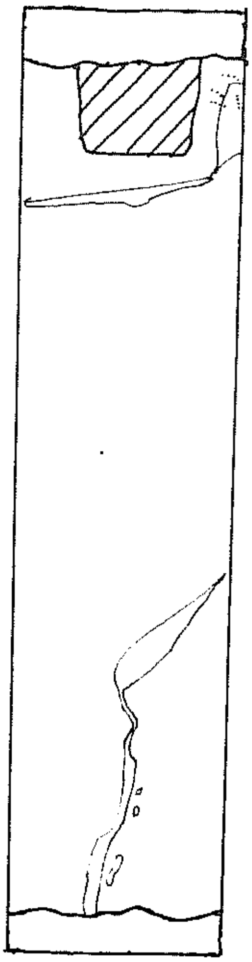


Depth: 8.5 - 9.0 m

Fissured, laminated, firm, 2.5 Y 5/6 silty clay (MARL). Little veining but sub. vert. manganese coated fissures and separation along some horiz. planes. Small displacements on fissures. Hcl reaction.

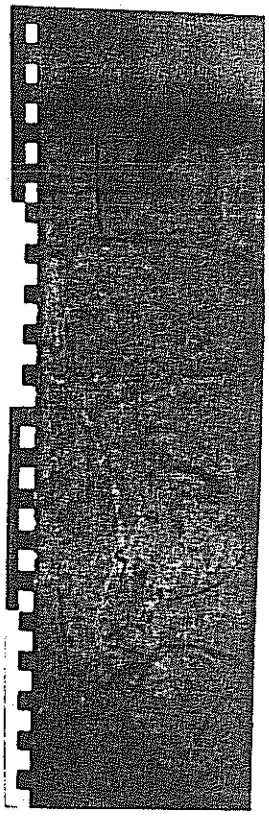
Note: slight downwarping in lower half due to drilling disturbance.

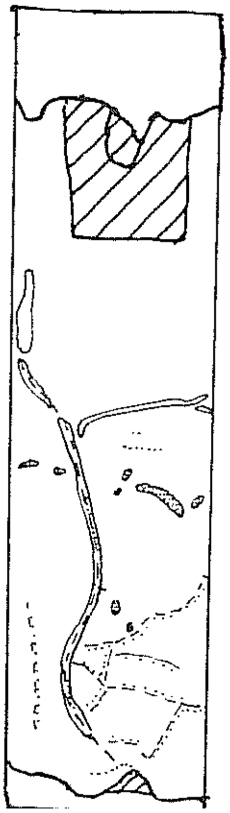




Depth: 9.5 - 10.0 m

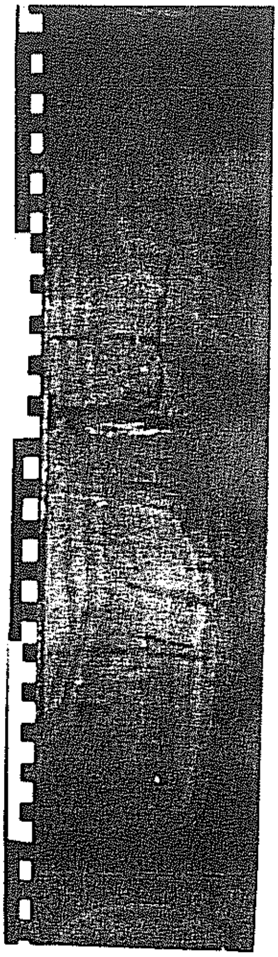
Soft-firm friable 10 YR 6/8 silty f. sand (SAND). Lower half has vein of 5 Y 6/2 clay. Upper 50 mm is soft (probably disturbed) 2.5 Y 5/6 silty CLAY with manganese staining. The SAND stratum is water bearing. Hcl reaction throughout.

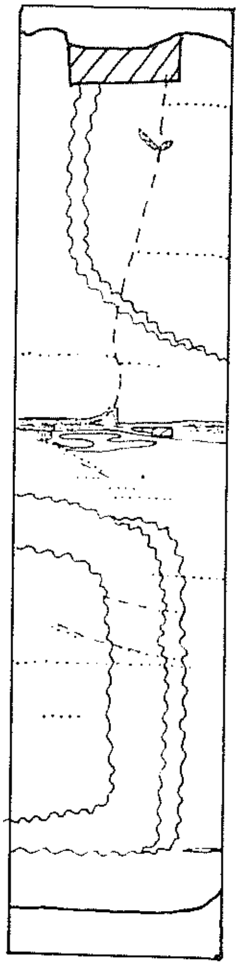




Depth: 10.5 - 11.0 m

Stiff-hard, fissured, mottled (2.5 Y 5/6 - 5 Y 6/2) slightly (f.) sandy, clayey silt (MARL). Sub. vert. veining of 5 Y 6/2 clay with manganese staining. Patches of iron oxide concentration. Some softening in top 10 cm due to drilling disturbance. Hcl reaction throughout.

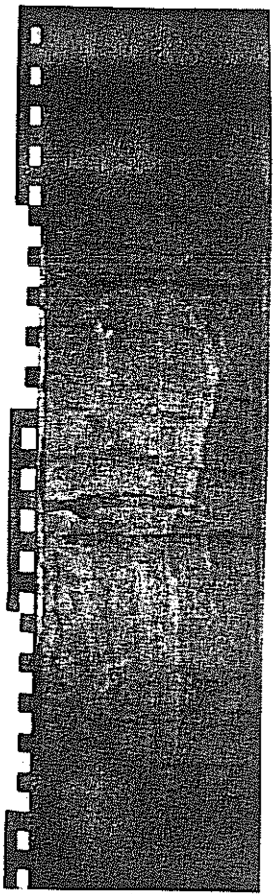


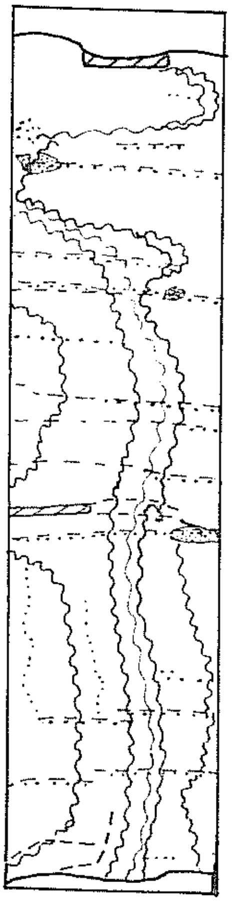


Depth: 11.5 - 12.0 m

Hard, slightly fissured, 2.5 Y 5/6 clayey silt (MARL). Few horiz. laminations contain manganese as well as carbonate and iron oxide deposits. Large scale circular banding either side of central open horiz. fissure. Sub. vert. fissure with 2-3 mm shear displacement extends upward and cuts both horiz. fissures and circular banding. Hcl reaction.

Note: opposite direction of percolation (?) in top and bottom halves.



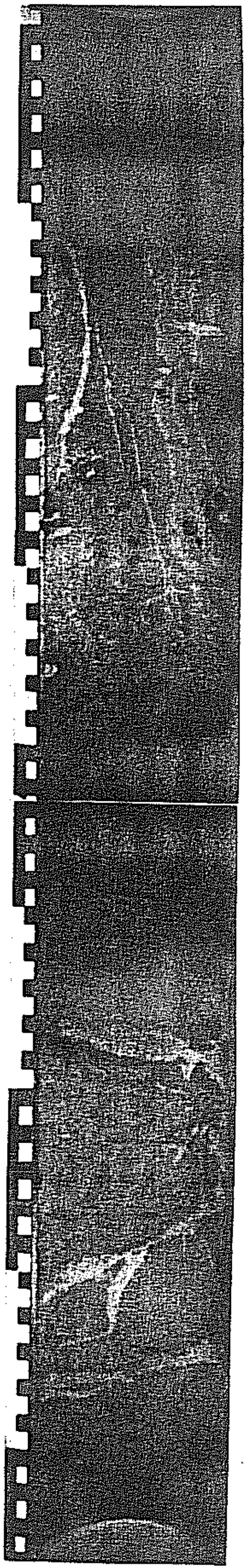


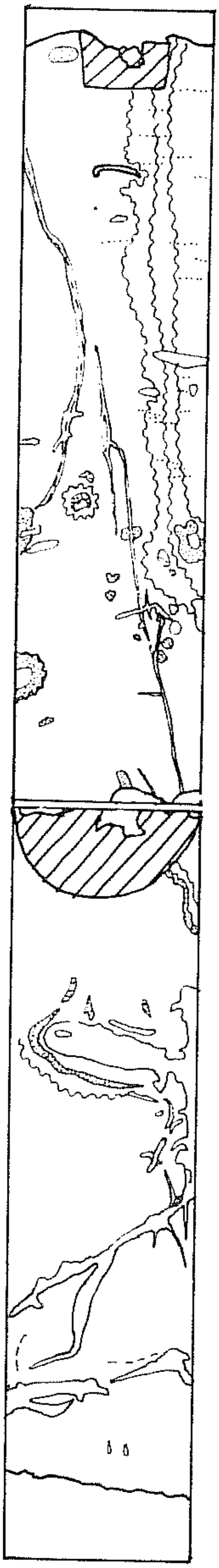
Depth: 12.5 - 13.0 m

As above (MARL) but few small sub vert. fissures. Horizontal fissuring more marked.

Note: circular banding pattern is cut and slightly displaced by horiz. fissures. Also note left to right direction of percolation (?).

Hcl reaction.





Depth: 14.5 - 15.0 m

Firm, slightly veined, 2.5 Y 5/6, clayey silt/silty clay (MARL) with sub. vert. veins of 5 Y 6/2 clay. Mainly vert. banding due to percolation (right to left?). Very thin laminations containing manganese in upper half of core. Patches of iron oxide concentrations in lower half of core. Small shear displacement along vert. vein.

Note: horiz. oriented fossil shell (top centre) detoured by banding.

Hcl reaction.

Depth: 15.0 - 15.5 m

As above (MARL) with more marked vert. and sub. horiz. veining of 5 Y 6/2 clay. Particularly large body of 5 Y 6/2 clay above centre of core with hard iron oxide-rich band around it. Upper 10 cm of core is soft probably due to drilling disturbance. Little manganese staining. Hcl reaction.

APPENDIX 1

1.1. B. H. Log - description, SPT, Index, M/C, Triax, Photo-Log EG 20/83

1.2. Mineralogy test data

1.3. Swelling data sheet

1.4. Consolidation data

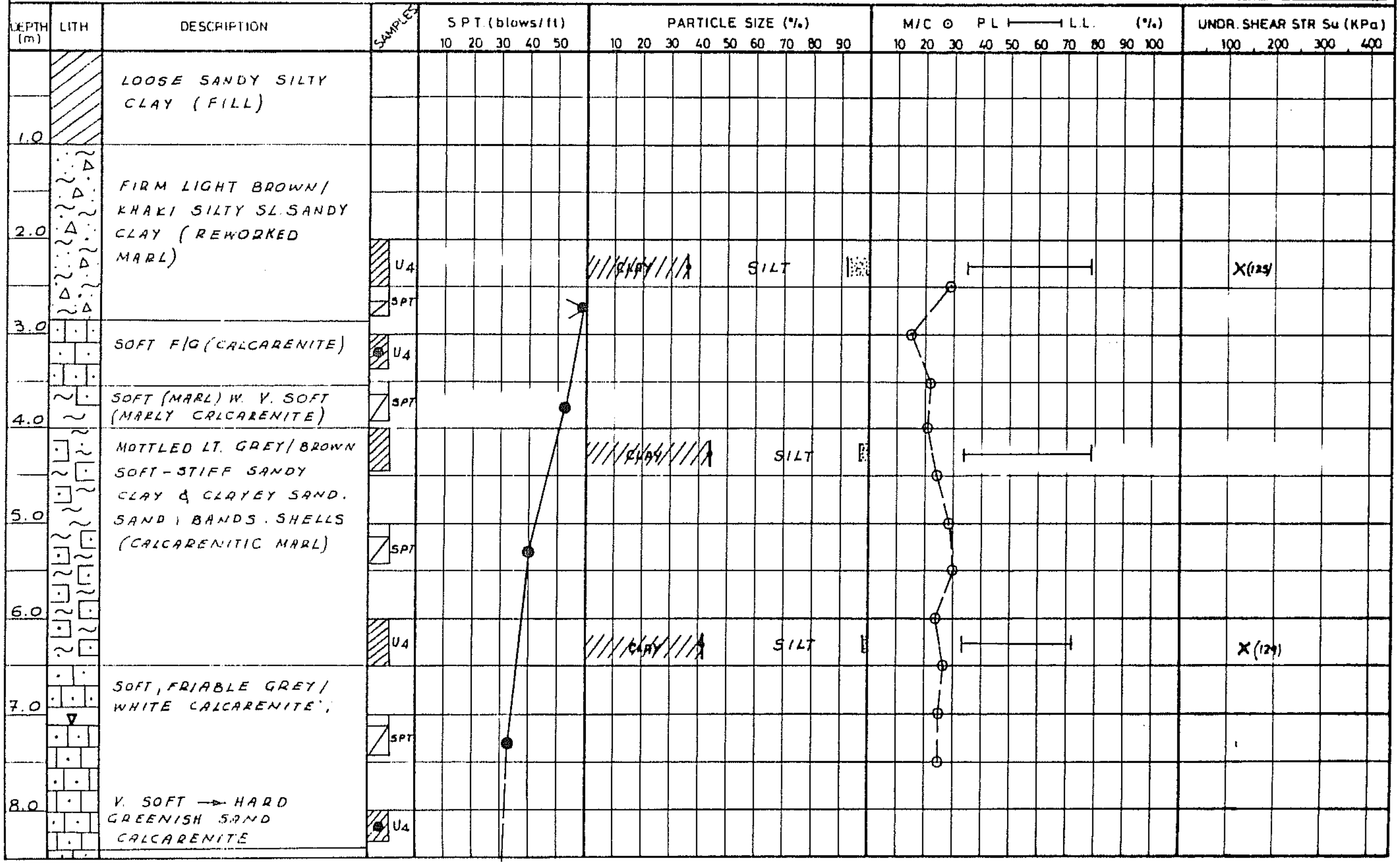
BH. No EG 7/82

SITE: MAKEDHONITISSA

GRID REF: S 28425 E, 38 89130 N G/L 187m. W/T 7.2 m

DATE: 12/5/82

PAGE: 1



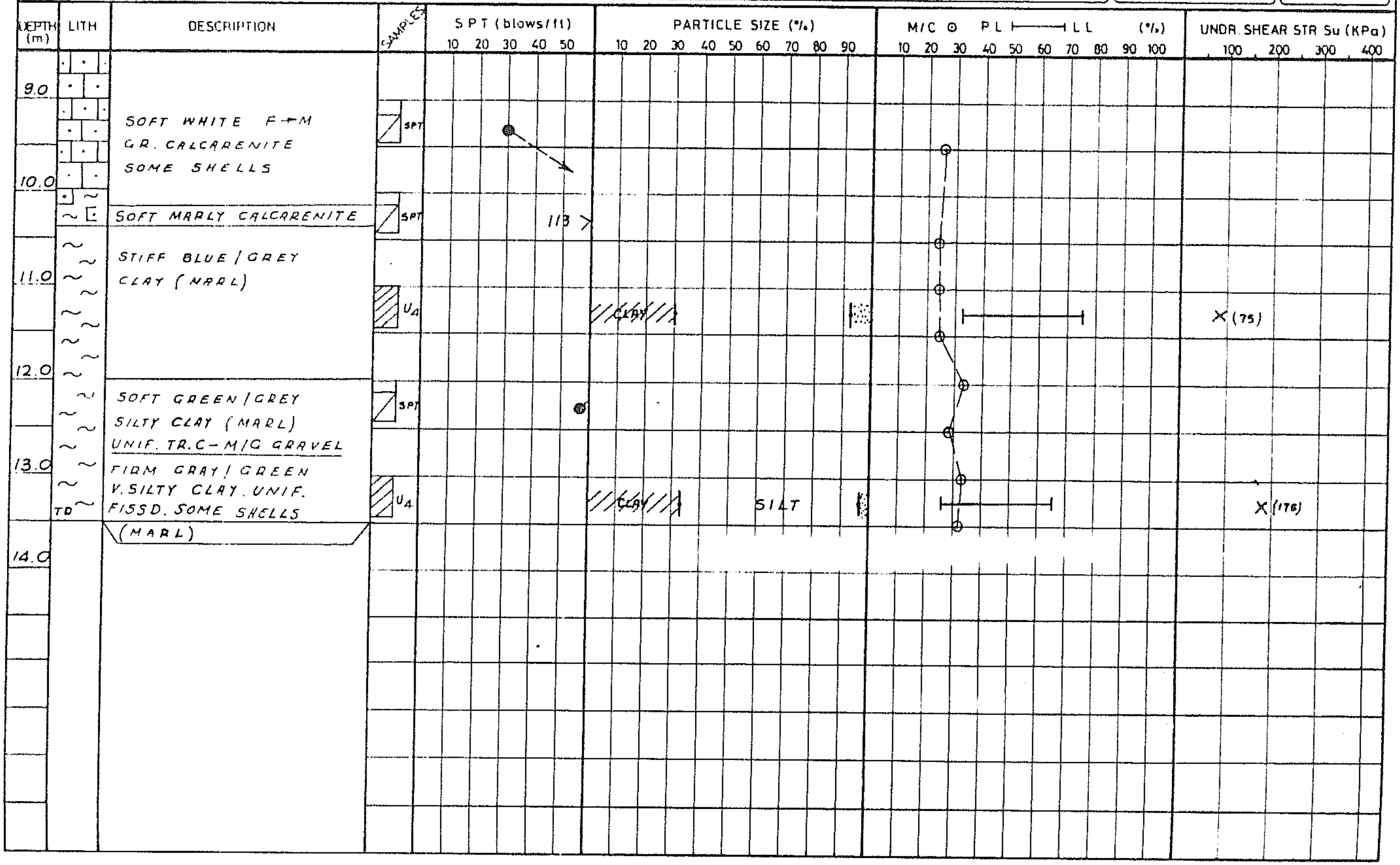
DEPTH (m)	DESCRIPTION
0.0–1.0	LOOSE SANDY SILTY CLAY (FILL)
1.0–3.0	FIRM LIGHT BROWN/ KHAKI SILTY SL. SANDY CLAY (REWORKED MARL)
3.0–3.7	SOFT F/G (CALCARENITE)
3.7–4.1	SOFT (MARL) W. V. SOFT (MARLY CALCARENITE)
4.1–6.5	MOTTLED LT. GREY/BROWN SOFT-STIFF SANDY CLAY & CLAYEY SAND. SAND ; BANDS. SHELLS (CALCARENITIC MARL)
6.5–8.0	SOFT, FRIABLE GREY/ WHITE CALCARENITE',
8.0–	V. SOFT → HARD GREENISH SAND CALCARENITE

BH No. EG 7/82

SITE: MAKEDHONITISSA
GRID REF: 5 284 25 E, 38 891 30 N G/L 187 m W/T 6.2 → 6.4 m

DATE: 12/5/82

PAGE: 2



SOFT WHITE F→M GR. CALCARENITE SOME SHELLS

SOFT MARLY CALCARENITE

STIFF BLUE/GREY CLAY (MARL)

SOFT GREEN/GREY SILTY CLAY (MARL) UNIF. TR.C–M/C GRAVEL

FIRM GRAY/GREEN V. SILTY CLAY. UNIF. FISSD. SOME SHELLS (MARL)

BH. No. EG 8/82 RE-DRILLED CLOSE BY DUE TO BROKEN BIT AT 4.00 m

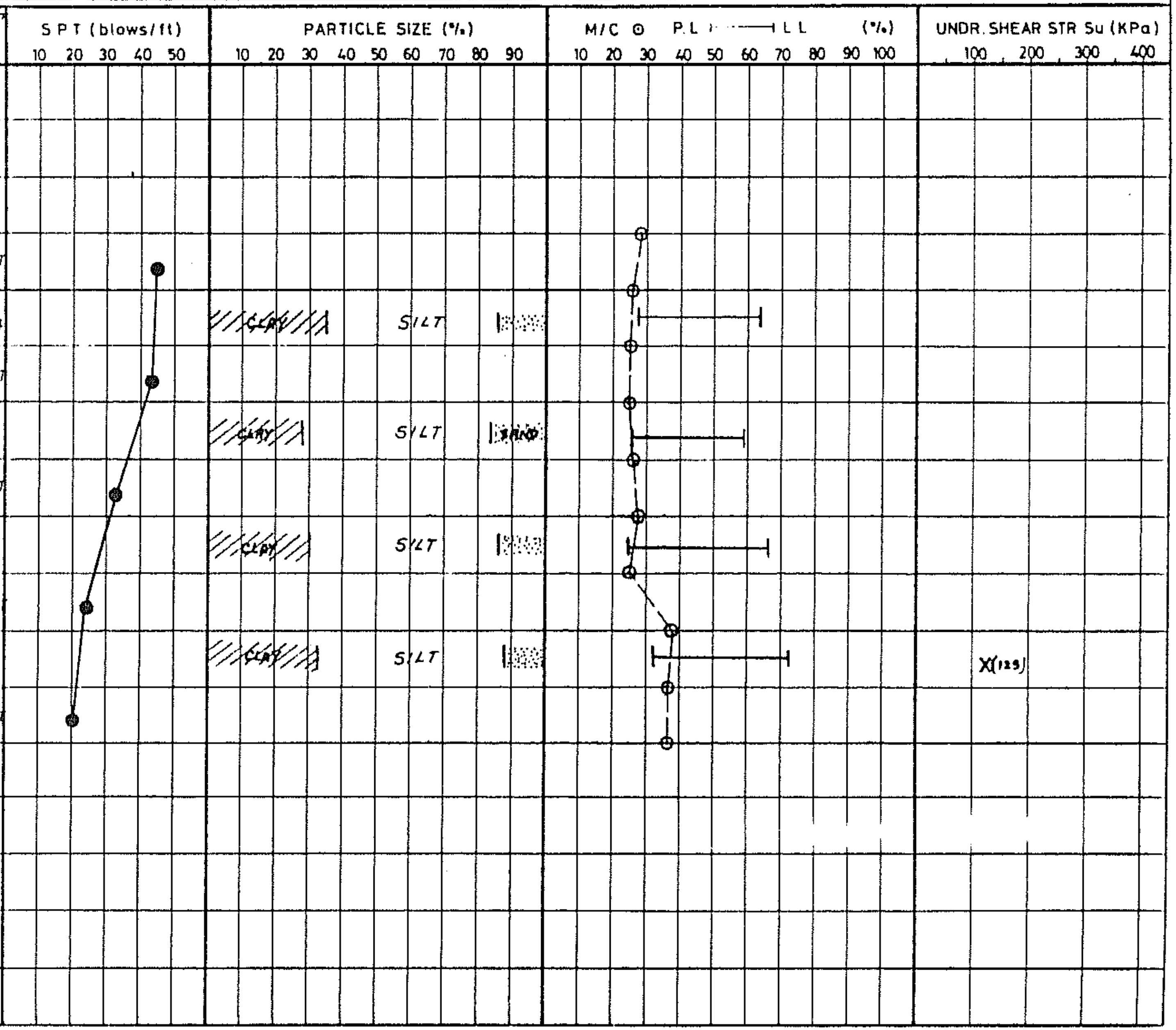
SITE: ONAL EXHIBITION CENTRE

GRID REF: 5 288 80 E, 58 903 40 N GIL 173 m. WIT DRY

DATE: 19/5/82

PAGE: 1

DEPTH (m)	LITH	DESCRIPTION	SAMPLES
		(TOPSOIL)	
1.0			
		HARD KHAKI SL SANDY SILTY CLAY. FISSd. W OXIDE (RED) AND MANGAN. (BLACK) STAINING (MARL)	
2.0			SPT
			U4
3.0			SPT
			U4
4.0			SPT
		V HARD RUBBLY M-C PARTLY CRYST. (CALCAR) LARGE SHELLS	U4
5.0		STIFF UNIF. LT. YELLOW SILTY CLAY W. F. SAND. LAMIN. OF GREY/YELLOW SILTY CLAY (MARL) TR. BLACK STAINING BECOMING GREY AT 6.0 but STILL MOTTLED	SPT
			U4
6.0	TD		SPT
7.0			



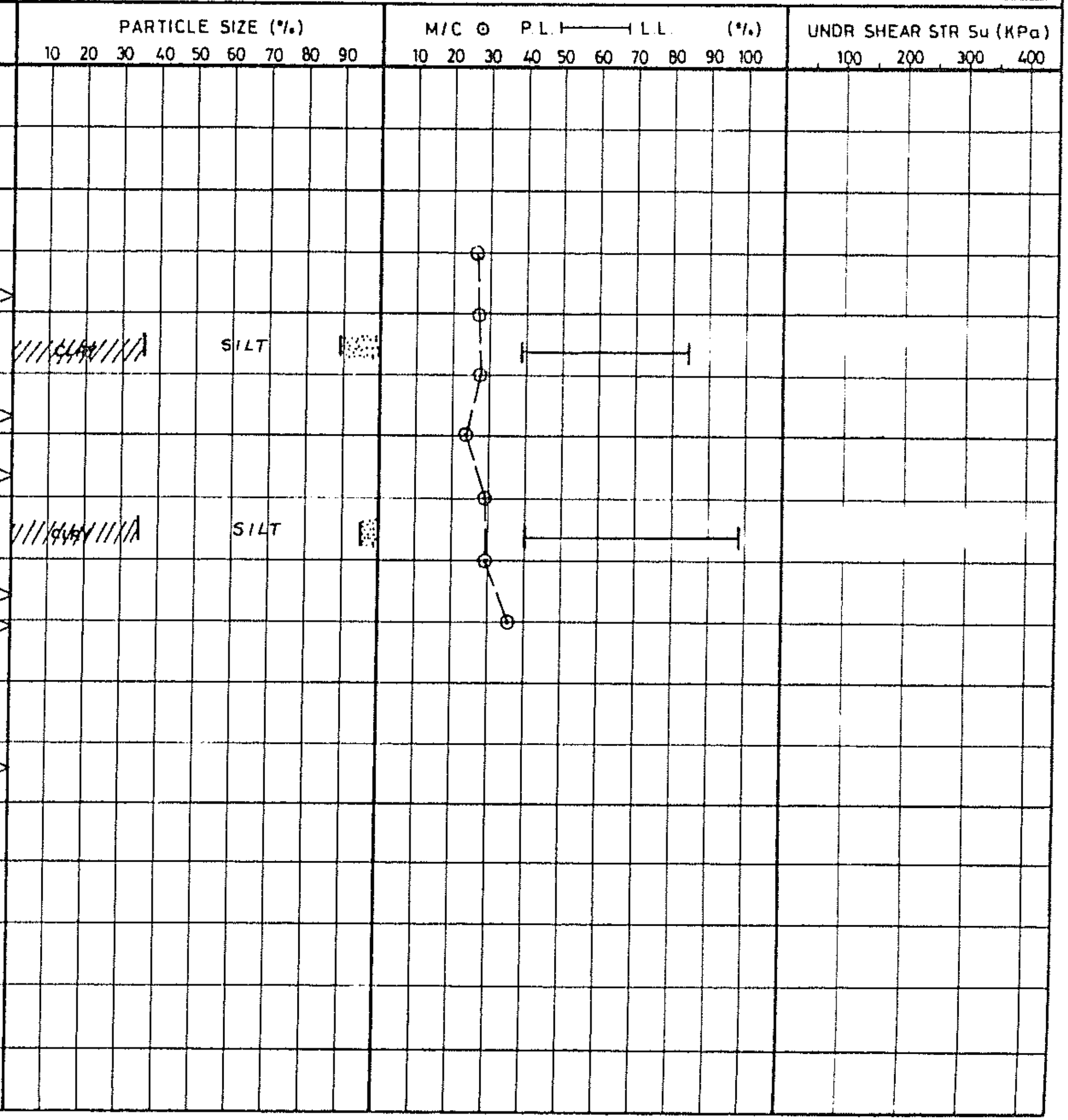
BH. No EG 9/82

SITE: ANTHOUPOLIS
GRID REF: 5 269 93 E, 38 86916 N G/L 230 m. W/T DRY

DATE: 20/5/82

PAGE: 1

DEPTH (m)	LITH	DESCRIPTION	SAMPLES	S P T (blows/ft)
1.0		DRY RUBBLY LT. RED/ BROWN STIFF SILTY CLAY (MARL)		
2.0		AS ABOVE, FISSd. W. MANGAN. STAINING & Ca CO_3 SOME SLICKENS (CLAY)	SPT U4	63>
3.0		AS ABOVE but DK. GREY	SPT	70>
		HARD FRIABLE INCR. Ca CO_3 (CLAY)	SPT	70>
4.0		AS ABOVE but FISSd. HARD GREEN/ BROWN/ WHITE 'SOAPY' TEXTURE AT 3.4 m (CLAY)	U4 SPT SPT	88> >
5.0		F/G. GREY/ BROWN MARLY CALCARENITE		
6.0	B/F P TD	FRIABLE WHITE/GREY BIOCLASTIC F → M. SST W IGNEOUS SAND & POCKETS OF MARL	SPT	>
7.0				

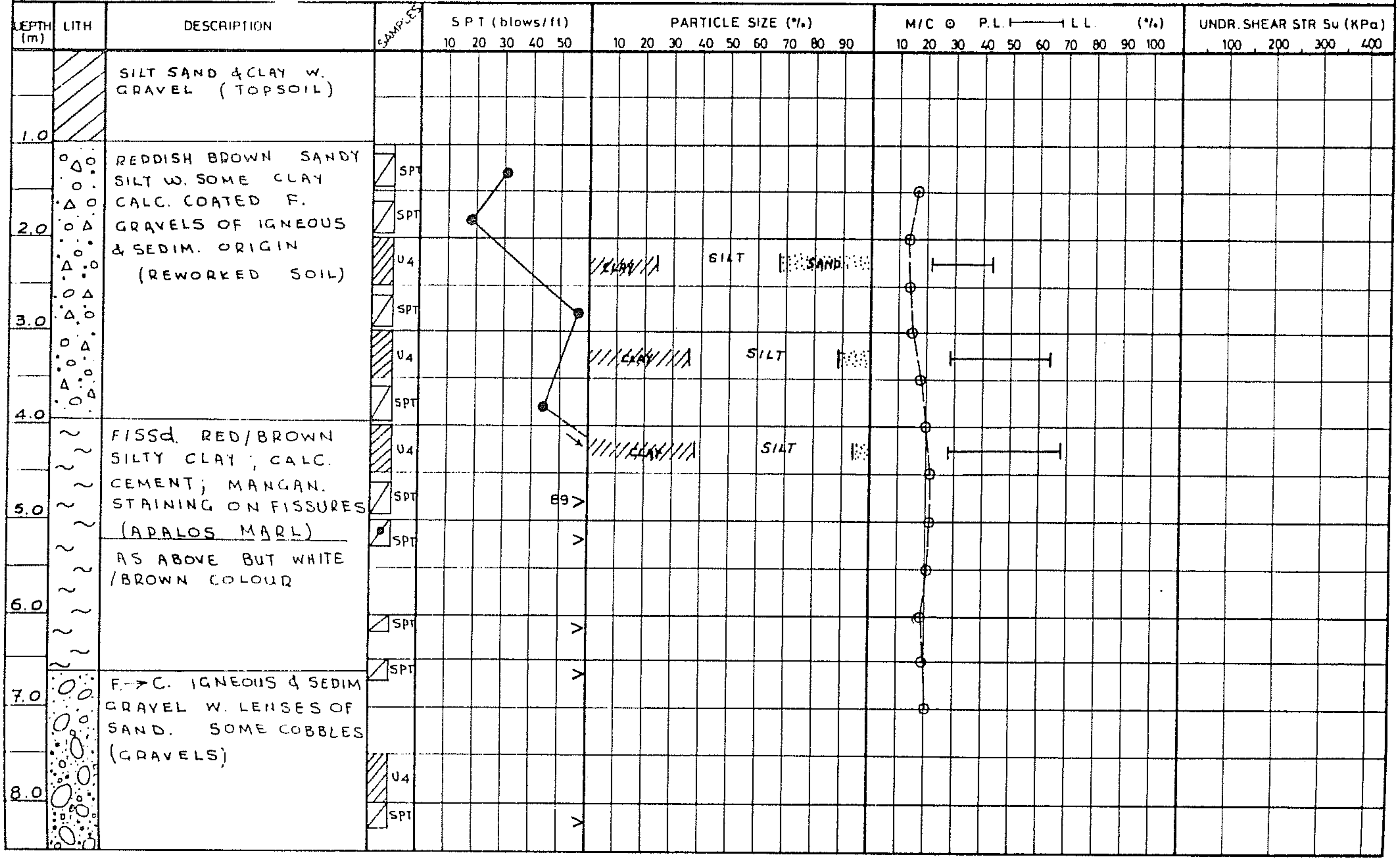


BH No. BH 13 / 82

SITE: ANTHOUPOLIS
GRID REF: 526118 E, 3886115 N G/L 248 m W/T DRY —

DATE: 7 / 6 / 82

PAGE: 1



DEPTH (m)	DESCRIPTION
0 – 1.0	SILT SAND & CLAY W. GRAVEL (TOPSOIL)
1.0 – 4.1	REDDISH BROWN SANDY SILT W. SOME CLAY CALC. COATED F. GRAVELS OF IGNEOUS & SEDIM. ORIGIN (REWORKED SOIL)
4.1 – 5.3	FISSd. RED/BROWN SILTY CLAY; CALC. CEMENT; MANGAN. STAINING ON FISSURES (ADALOS MARL)
5.3 – 6.8	AS ABOVE BUT WHITE /BROWN COLOUR
6.8 –	F.→C. IGNEOUS & SEDIM GRAVEL W. LENSES OF SAND. SOME COBBLES (GRAVELS)

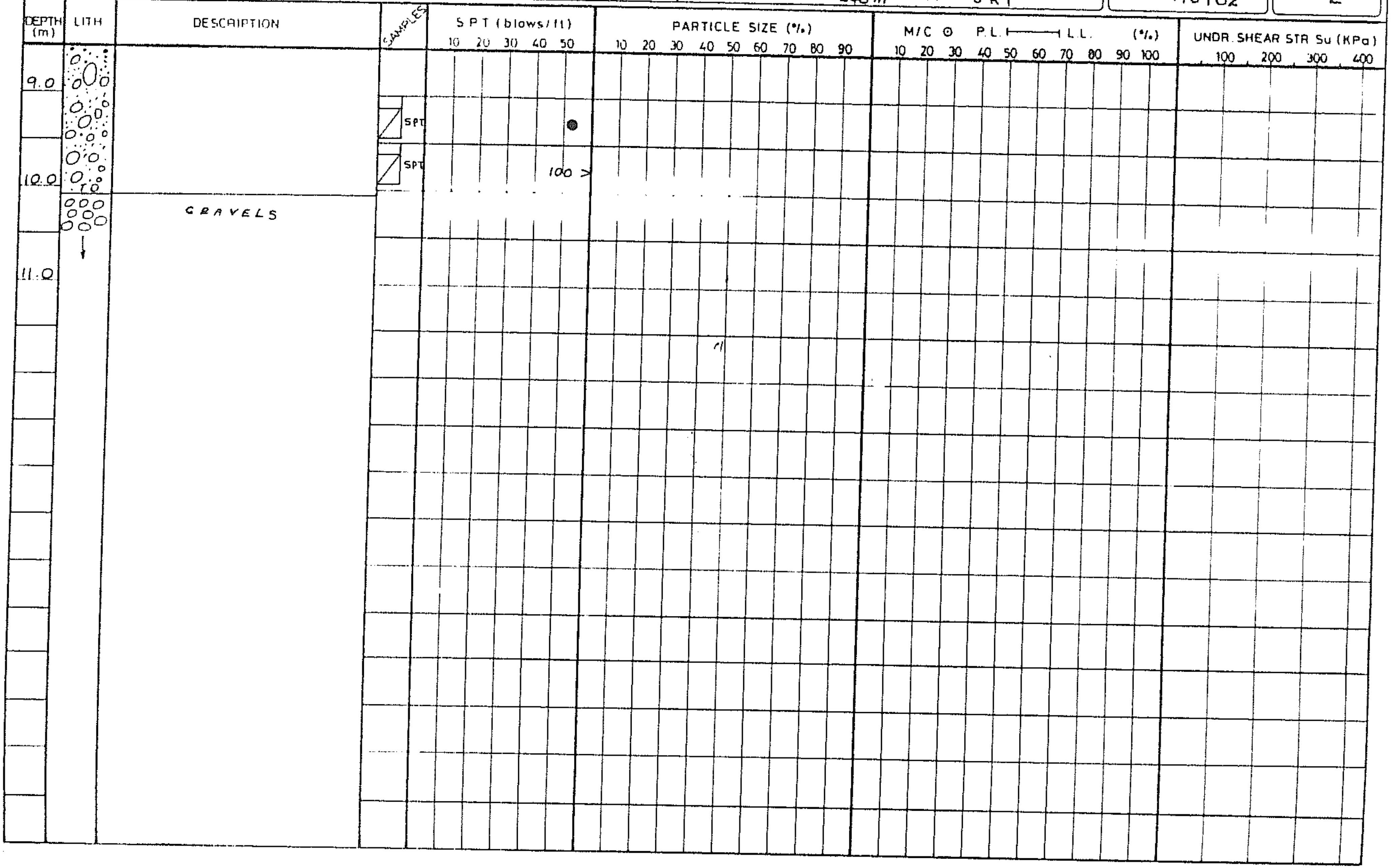
BH No BH 13/82

SITE: ANTHOUPOLIS

GRID REF: 5 261 18 E, 88 861 15 N G/L 248 m W/T DRY

DATE: 7/6/82

PAGE: 2

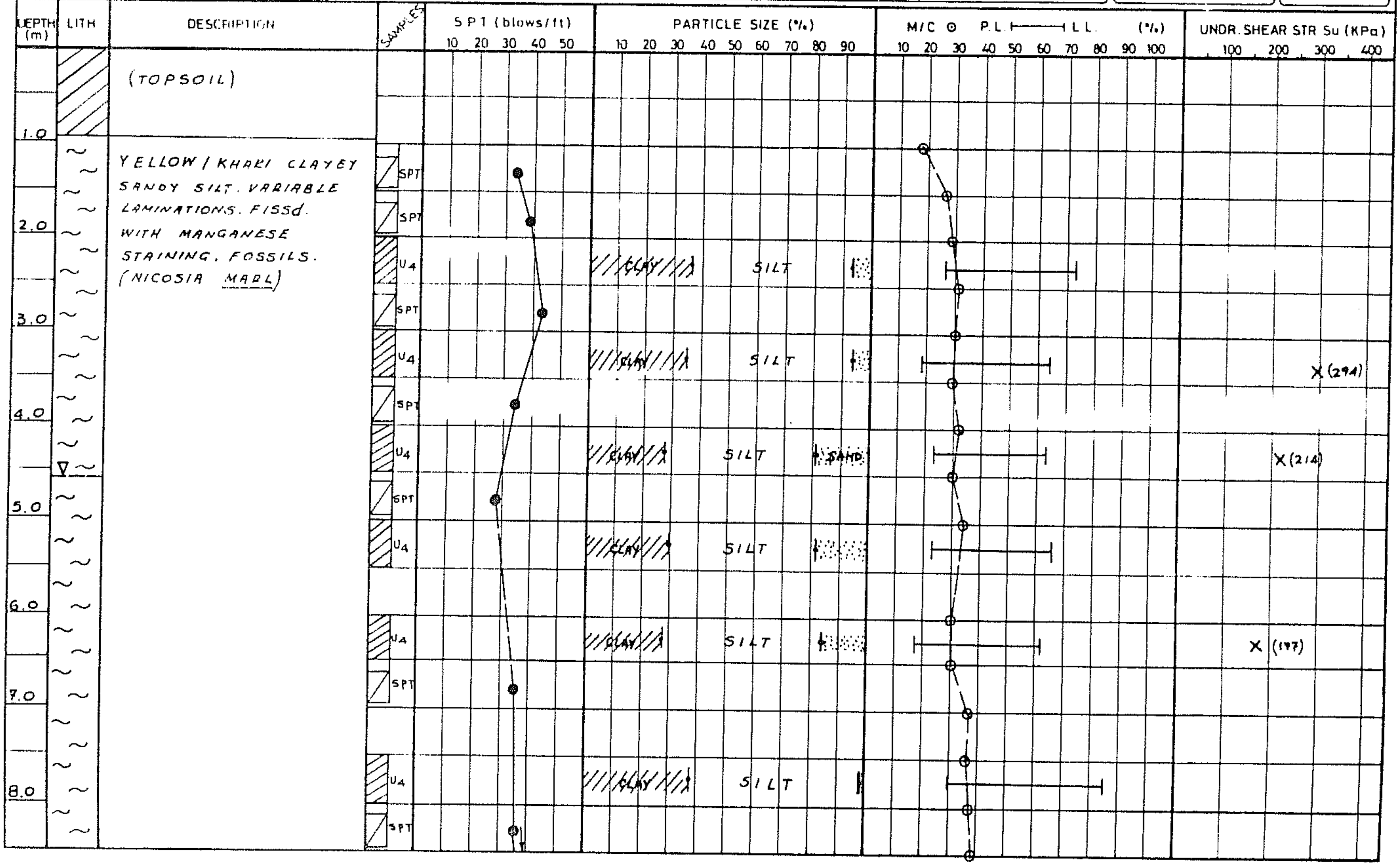


BH No EG 14/82

SITE: LYKAVITOS SCHOOL
GRID REF: 533715 E, 389151oN G/L 146 m. W/T 3.5 – 4.7

DATE: 10/6/82

PAGE: 1



(TOPSOIL)

YELLOW / KHAKI CLAYEY SANDY SILT. VARIABLE LAMINATIONS. FISSd. WITH MANGANESE STAINING. FOSSILS. (NICOSIA MARL)

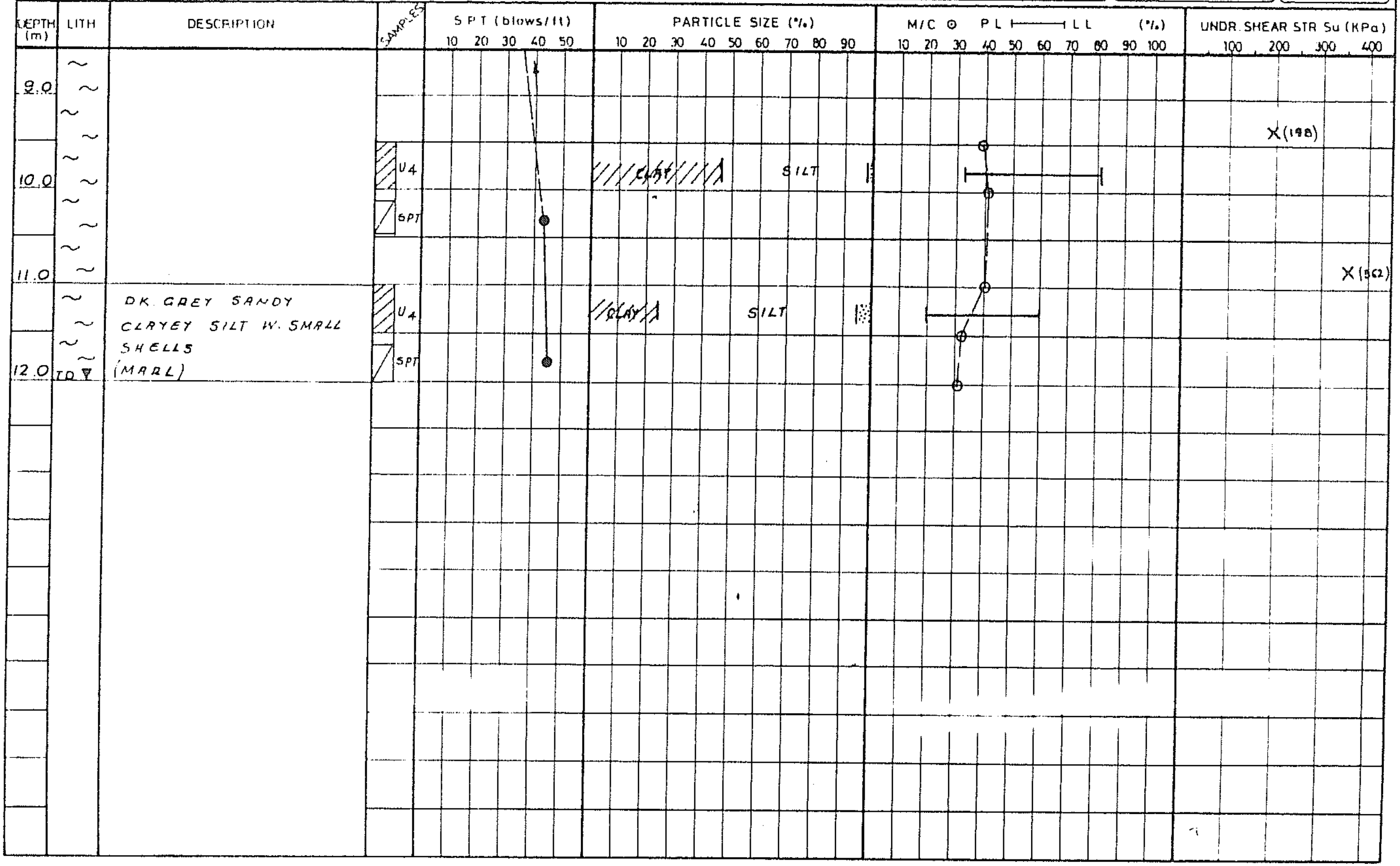
BH No EG 14/82

SITE: LYKAVITOS SCHOOL

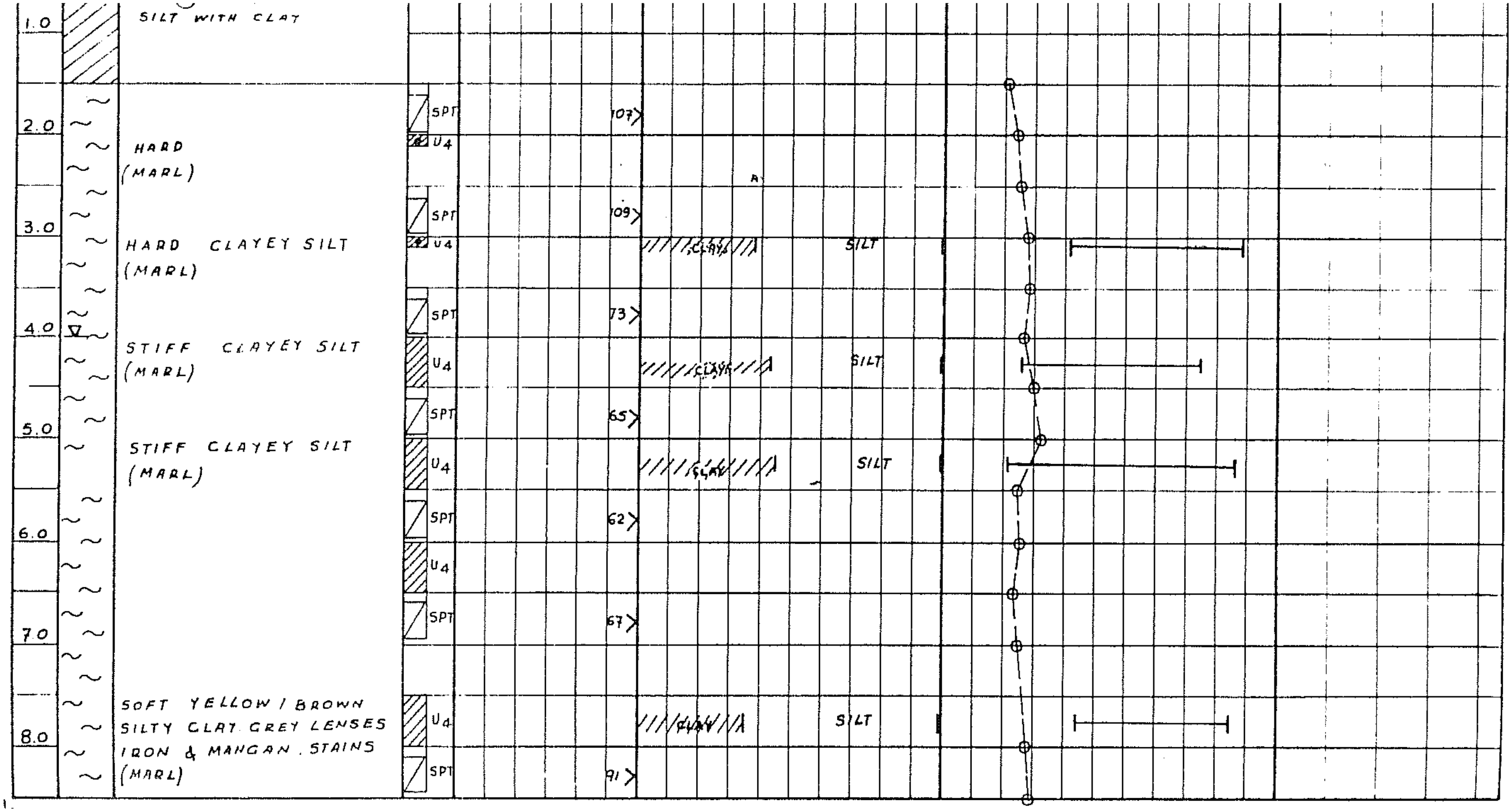
GRID REF: 5 33715 E, 38 91310 N G/L 146 m. W/T 3.5 - 4.7

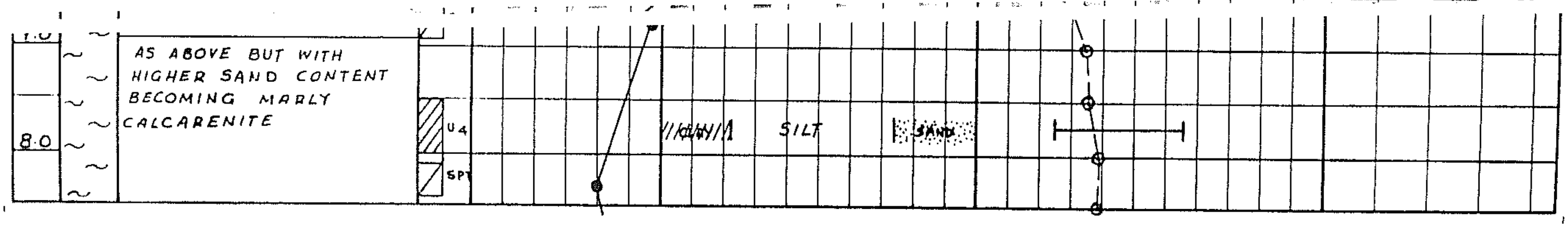
DATE. 10/6/82

PAGE: 2



DK. GREY SANDY CLAYEY SILT W. SMALL SHELLS (MARL)


1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
SILT WITH CLAY
HARD
(MARL)
HARD CLAYEY SILT
(MARL)
STIFF CLAYEY SILT
(MARL)
STIFF CLAYEY SILT
(MARL)
SOFT YELLOW / BROWN
SILTY CLAY GREY LENSES
IRON & MANGAN. STAINS
(MARL)
SPT
U4
107
109
73
65
62
67
91
CLAY
SILT

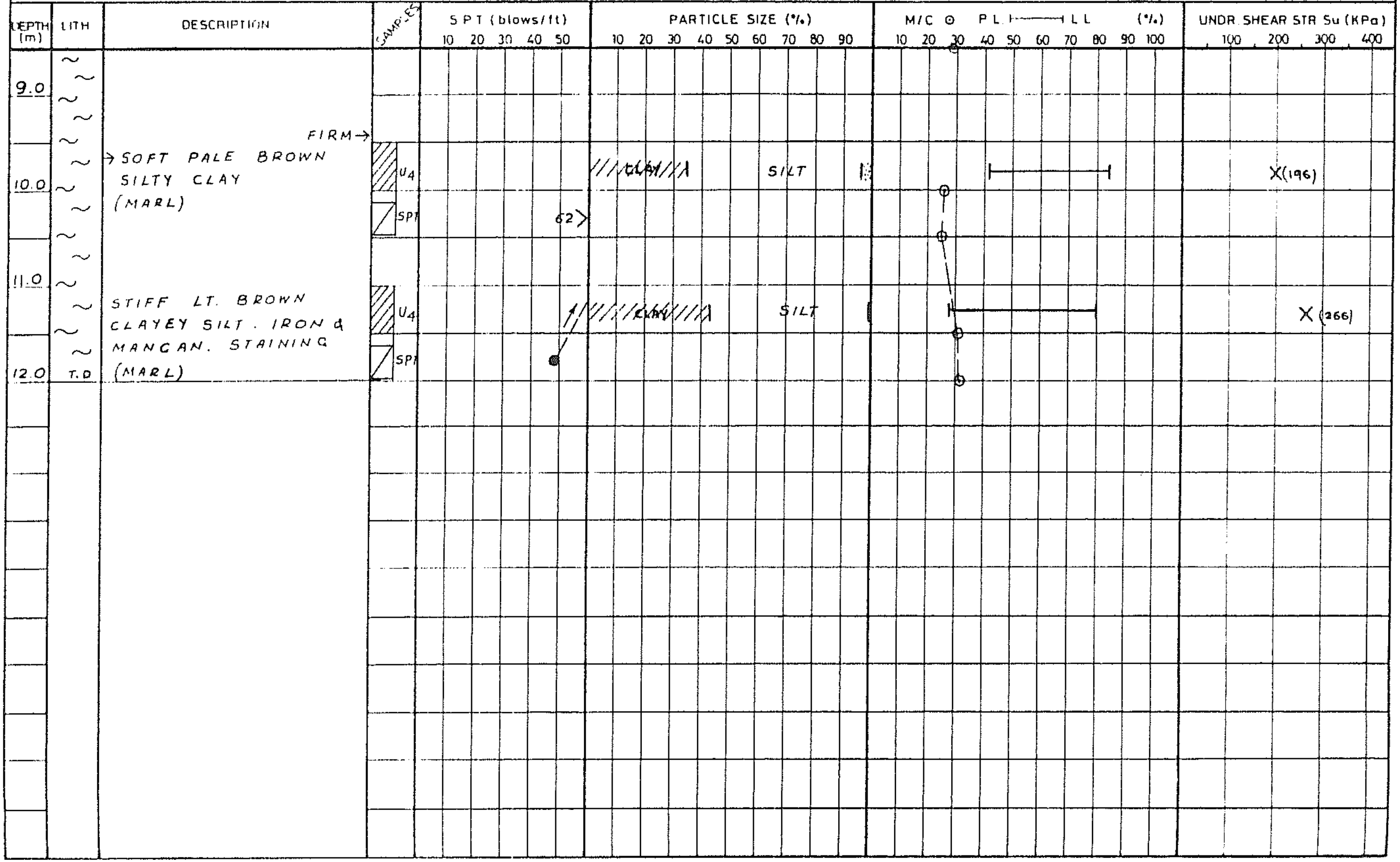

8.0
AS ABOVE BUT WITH
HIGHER SAND CONTENT
BECOMING MARLY
CALCARENITE
U4
SPT
CLAY
SILT
SAND

BH No EG 18/82

SITE. AYIA VARVARA
GRID REF. 535794 E, 3892607 N G/L 139 m W/T 3.5 – 4.4 m

DATE: 30/6/82

PAGE: 2



FIRM→

→SOFT PALE BROWN SILTY CLAY (MARL)

STIFF LT. BROWN CLAYEY SILT. IRON & MANGAN. STAINING (MARL)

Borehole EG	Sample Depth	Calcite	Dolomite	Quartz	Feldspar	Ca-montmor	Mica	Chlorite	Gypsum
8/82	2.0-2.5	**	Tr.	**	*	Present	Present	Present	N. M.
	4.0-4.5	**	**	*	Tr.	"	"	"	"
	5.0- 5.5	***	*	*	*	"	"	"	"
9/82	3.5-4.0	***	N.D.	*	Tr.	"	"	"	"
14/82	2.0-2.5	**	*	*	*	"	"	"	"
	6.0-6.5	***	**	**	**	"	"	"	"
	9.5-10.0	***	*	**	*	"	"	"	"
	11.0-11.5	**	**	*	*	"	"	"	"
18/82	3.0-3.5	**	*	*	*	"	"	"	"
	11.0-11.5	**	**	**	*	"	"	"	"
7/82	2.0-2.5	***	**	**	***	**	*	*	N.D.
	4.0-4.5	***	N. D.	**	**	**	N.D.	*	N.D.
	11.0-11.5	***	Tr.	***	*	*	*	*	N.D.
	13.0-13.5	***	Tr.	*	Tr.	**	*	*	N.D.
16/82	2.0-2.5	***	**	**	*	**	N. D.	*	N. D.
	4.0-4.5	***	*	*	*	*	*	*	N. D.
	5.0-5.5	***	*	*	Tr	*	N.D.	*	N. D.
	6.0-6.5	***	*	**	Tr	*	N.D.	N.D.	*
15/82	2.0-3.5	***	*	**	*	**	*	N.D.	N.D.
	7.5-8.0	***	Tr	**	Tr	*	*	N.D.	N.D.
	9.5-10.0	***	*	*	*	*	N.D.	*	N.D.
17/82	3.0-3.5	***	*	**	*	*	*	N.D.	N.D.
	4.0-4.5	***	*	**	*	**	N.D.	*	N.D.
	5.0-5.5	*	*	**	*	**	*	*	N.D.
	6.0-6.5	***	**	**	*	*	*	N.D.	Tr.

N.M. Not Measured
N.D. Not detected
Relative X-ray intensities:

***	Strong
**	Medium
*	Weak
Tr	Trace

Table 1. Mineralogical composition (general) of samples from the Nicosia Marl, carried out at B.G.S.

BH No	(m) Sample Depth	Total carbonate (%)	Quartz (%)	Ca-montmor. (%)
EG 8/82	2.0 – 2.5	26	8	19(150)
	4.0 – 4.5	36	6	17(136)
	5.0 – 5.5	32	6	20(158)
EG 9/82	3.5 – 4.0	32	4	31(251)
EG 14/82	2.0 – 2.5	32	5	24(193)
	6.0 – 6.5	39	7	14(114)
	9.5 – 10.0	24	8	24(192)
	11.0 – 11.5	32	6	18(140)
EG 18/82	3.0 – 3.5	45	5	24(189)
	11.0 – 11.5	38	8	22(179)
EG 16/82	2.0 – 2.5	20	9	22(179)
	4.0 – 4.5	21	9	21(168)
	11.0 – 11.5	30	11	16(131)
	13.0 – 13.5	29	4	19(149)
EG 16/82	2.0 – 2.5	33	6	25(195)
	4.0 – 4.5	45	5	16(126)
	5.0 – 5.5	55	5	10(84)
	6.0 – 6.5	58	6	11(86)
EG 15/82	3.0 – 3.5	35	7	28(222)
	7.5 – 8.0	55	6	15(122)
	9.5 – 10.0	54	5	13(96)
EG 17/82	3.0 – 3.5	41	7	16(128)
	4.0 – 4.5	29	9	21(180)
	5.0 – 5.5	25	6	24(190)
	6.0 – 6.5	44	7	14(115)

Figures in brackets are Surface Areas in m^2/g.

Table 2. Total carbonate, quartz and Ca-montmorillonite contents of samples from the Nicosia Marl, carried out at B.G.S.

NICOSIA MARLS, BG.S. SWELLING PRESSURE TEST DATA

SAMPLE B/H	SITE	DEPTH in m	SWELL PRESSURE in KPa	MOISTURE CONTENT In %			BULK DENSITY g/cc		DRY DENSITY g/cc
				PRETEST	POSTTEST	SHAVINGS	PRETEST	POSTTEST	
7/82	MAKEDONITISSA	2.0 — 2.5	16.06	34.14	35.76	30.86	1.853	1.876	1.382
		4.0 — 4.5	X	—	—	31.45	—	—	—
		11.0 — 11.5	3.68	30.77	35.20	31.36	1.802	1.863	1.378
		13.0 — 13.5	X	—	—	33.48	—	—	—
8/82	EKTHESI	2.0 — 2.5	33.73	30.83	30.98	29.41	1.933	1.955	1.493
		3.0 — 3.5	X	—	—	24.03	—	—	—
		4.0 — 4.5	8.03	34.82	35.71	34.24	1.760	1.772	1.306
		5.0 — 5.5	20.08	35.84	37.32	34.47	1.832	1.852	1.350
9/82	ANTHOUPOLIS	3.5 — 4.0	X	—	—	28.90	—	—	—
14/82	LYKAVITOS	2.0 — 2.5	40.81	30.26	31.80	28.56	1.924	1.947	1.477
		3.0 — 3.5	X	—	—	29.66	—	—	—
		4.0 — 4.5	X	—	—	33.40	—	—	—
		5.0 — 5.5	17.82	27.75	30.07	28.89	1.901	1.936	1.488
		6.0 — 6.5	16.00	30.50	32.72	29.53	1.843	1.874	1.412
		7.5 — 8.0	77.49	37.72	39.50	34.80	1.862	1.886	1.352
		9.5 — 10.0	51.39	41.00	42.50	39.62	1.811	1.820	1.280
		11.0 — 11.5	29.31	33.56	34.87	—	1.874	1.892	1.403
15/82	PRODUCTIVITY CENTRE	3.0 — 3.5	X	—	—	31.05	—	—	—
		7.5 — 8.0	X	—	—	31.00	—	—	—
		9.5 — 10.0	X	—	—	28.77	—	—	—
16/82	EYLENJA	2.0 — 2.5	X	—	—	24.94	—	—	—
		4.0 — 4.5	X	—	—	17.35	—	—	—
		5.0 — 5.5	16.46	23.41	29.25	25.27	1.645	1.720	1.330
		6.0 — 6.5	14.86	22.56	23.94	21.19	1.826	1.847	1.490
17/82	AYIOS NICOLAOS	3.0 — 3.5	14.69	27.18	28.81	29.60	1.922	1.947	1.510
		4.0 — 4.5	39.56	34.26	35.50	36.48	1.876	1.894	1.400
		5.0 — 5.5	37.74	34.40	35.98	35.40	1.849	1.871	1.380
		6.0 — 6.5	22.08	26.63	27.44	26.70	1.986	2.001	1.570
18/82	AYIA VARVARA	3.0 — 3.5	68.66	23.80	24.56	(25.60?)	1.884	1.895	1.520
		5.0 — 5.5	55.97	32.78	35.45	34.03	1.861	1.899	1.400
		7.5 — 8.0	X	—	—	29.59	—	—	—
		11.0 — 11.5	35.16	32.27	34.02	29.05	1.884	1.908	1.420

G.S.D.(E.Geol.)D.P. 30/83

X—SAMPLE PREPARATION UNSUCCESSFUL

NICOSIA MARLS
DERIVED CONSOLIDATION DATA

□ G.S.D. Test
* BG.S. Test

BH. No	DEPTH (m)	NAT M/C (°/•)	eo	Po' (estimtd) (KPa)	Psw' (KPa)	Cc LAB.	Cc FIELD	Gs	Pc' Min Prob	Pc' Max Prob	Pc' Most Prob	O.C.R. Min Prob.	O.C.R. Max Prob	O.C.R. Most Prob
EG 7/82*	2·0–2·5		0·542	19	16·1	0.12	0·12	0·032	150	700	310	7·9	36·8	16·3
EG 8/82□*	4·0–4·5	32·9* 32·9□	0·920* 0·922□	37* 37□	8·0* 14·5□	0·166* 0·273□	0·176* 0·283□	0·037* 0·056□	150* 860□	680* 1300□	250* 1020□	4·1* 23·2□	18·4* 35·1□	6·8* 28·0□
EG 8/82□	5·0–5·5	37·1	0·986	94	22·5	0·365	0·408	0·081	610	1400	900	6·5	14·9	9·5
EG14/82□	2·0–2·5	29·7	0·862	46	87·0	0·174	——	0·069	320?	1300	600	7·0?	28·3	13·2
EG14/82□	3·0–3·5	29·4	0·782	61	56·0	0·160	——	0·063	370	1500	760	6·1?	48·4	12·6
EG14/82□	4·0–4·5	31·0	0·917	80	17·0	0·240	0·240	0·049	600	1400	650	7·5	17·5	8·1
EG14/82□	5·0–5·5	33·0	0·879	100	37·0	0·319	0·354	0·059	750	1500	1120	7·5	15·0	11·2
EG14/82□	7·5–8·0	36·5	0·940	145	170·0	0·258	——	0·091	570?	1200	870	3·9	8·3	6·1
EG14/82□*	9·5–10·0	39·5	1·000* 1·120□	165* 165□	51·4* 56·0□	0·350* 0·360□	0·384* 0·360□	0·075* 0·106□	160* 840□	600* 1250□	260* 840□	1·0* 5·3□	3·6* 7·6□	1·6* 5·3□
EG14/82□	11·0–11·5	35·3	0·906	135	70·0	0·210	0·212	0·060	1070	1600	1200	7·9	11·9	8·9
EG15/82□	7·0–7·5	36·0	1·108	105	10·5	0·456	0·500	0·057	750	1700	1030	7·1	16·2	9·5
EG15/82□	9·5–10·0	31·0	0·885	125	23·0	0·292	0·324	0·06	640	1900	1000	5·1	15·2	8·2
EG16/82□	5·0–5·5	21·0	1·107	87	11·2	0·476	0·526	0075	450	1400	580	5·2	16·1	6·6
EG 16/82□*	6·0–6·5	26·5	0·725□	45□	18·5□	0·233□	0·283□	0·048□	280□	1600□	650□	6·2□	35·6□	14·4□
EG17/82□	3·0–3·5	31·5	0·765	52	28·0	0·135	0·135	0·066	260?	800	300	5·0?	15·4	5·6
EG17/82□	4·0–4·5	35·0	0·883	65	17·5	0·226	0·226	0·084	160?	360	175	2.5	5·5	2·7
EG17/82□	5·0–5·5	35·0	0·982	75	21·5	0·295	0·295	0·166	500?	1200	530	6·7?	16·0	7·2
EG18/82*	3·0–3·5	28·0	0·724	——	68·7	0·120	——	0·044	——	——	——	——	——	——
EG 18/82□	7·5–8·0	28·0	0·783	105	28	0·193	0·202	0·064	255	1000	360	2·4	9·5	3·4

G.S.D. (E.Geol.) D.P. 21/83

APPENDIX 2

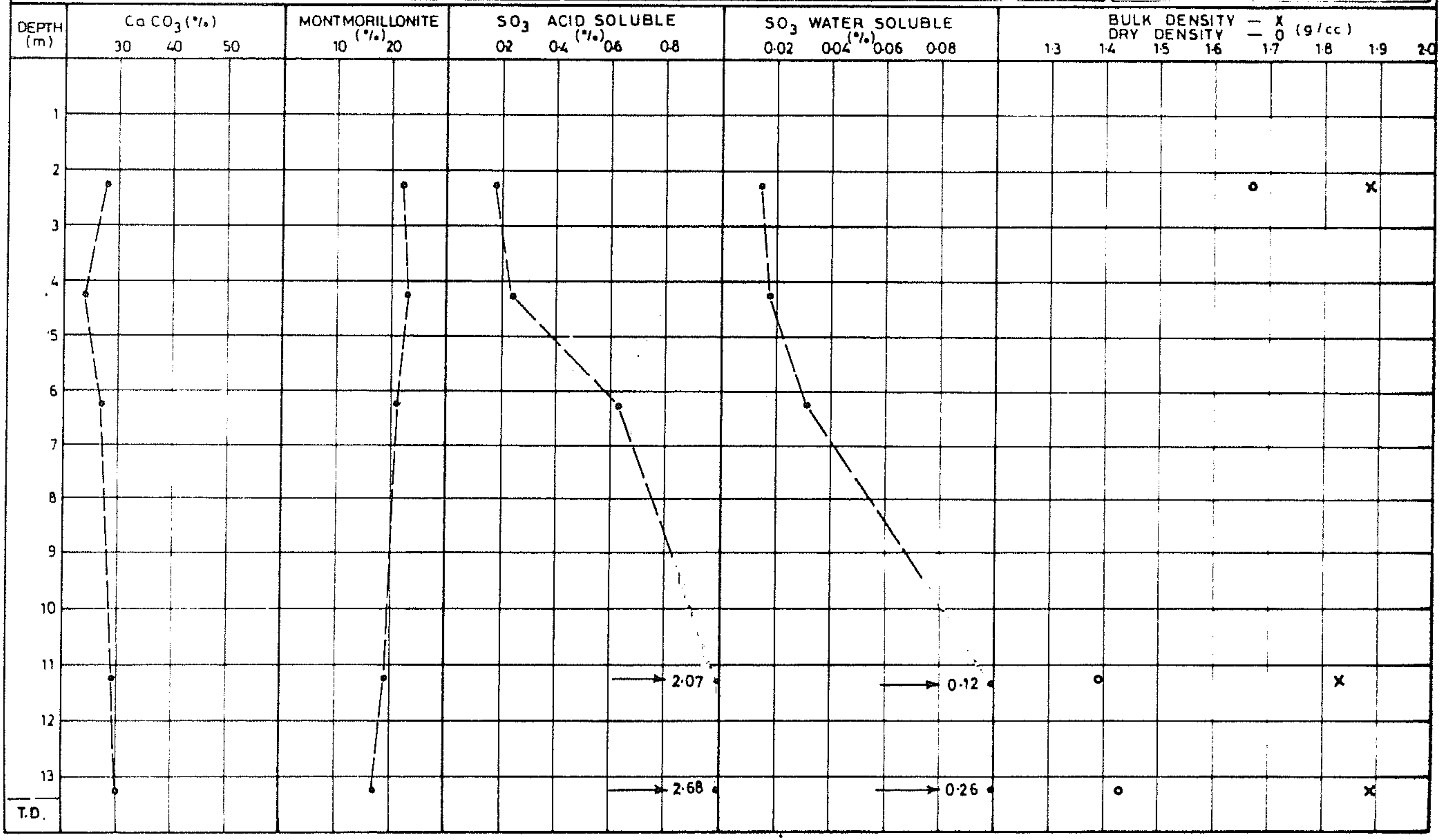
NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH. No EG 7/82

SITE MAKEDHONITISSA

GRID REF: s 284 25 E, 3889130 N G/L 187 m W/T 7·2 m

DATE 12/5/82



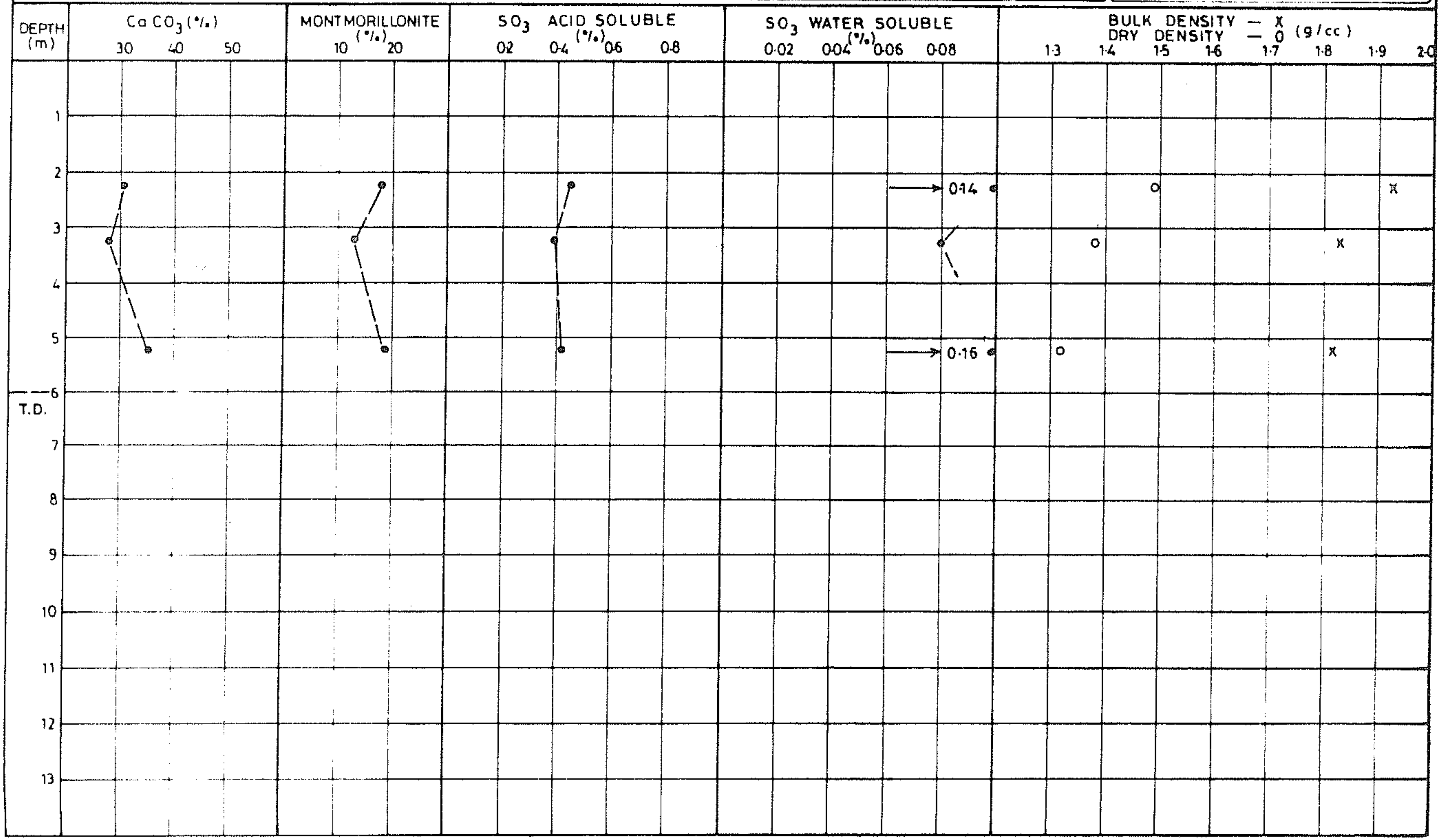
APP. 2.1

NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No. EG 8/82

SITE NATIONAL EXHIBITION CENTRE
GRID REF 5 288 80 E , 38 903 45 N G/L 173 m W/T DRY

DATE 19/5/82



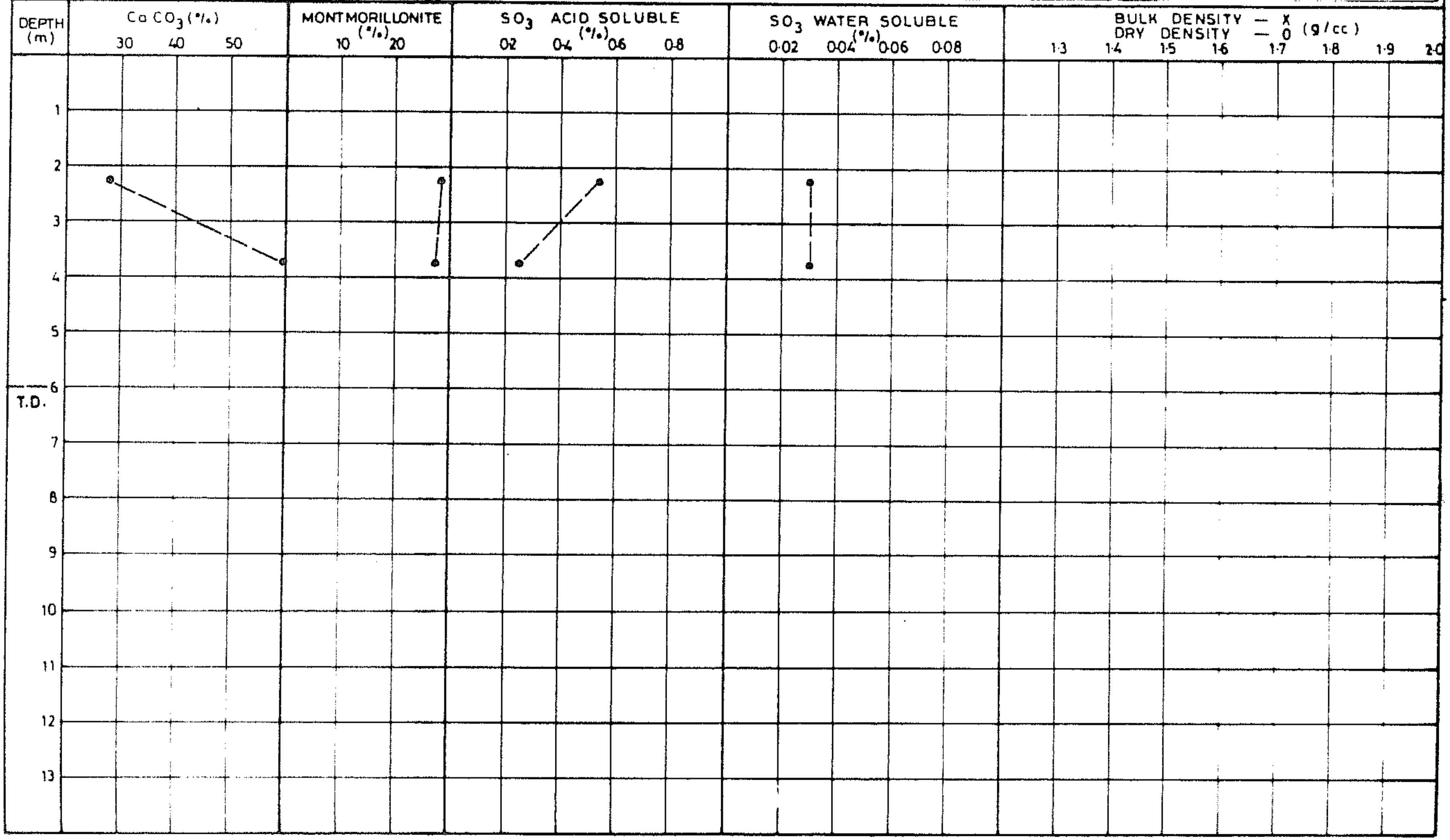
APP. 2.1

NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No. EG 9/82

SITE ANTHOUPOLIS
GRID REF: 5 269 93 E , 38 869 15 N G/L 230 m W/T DRY

DATE 20/5/82



APP. 2.1

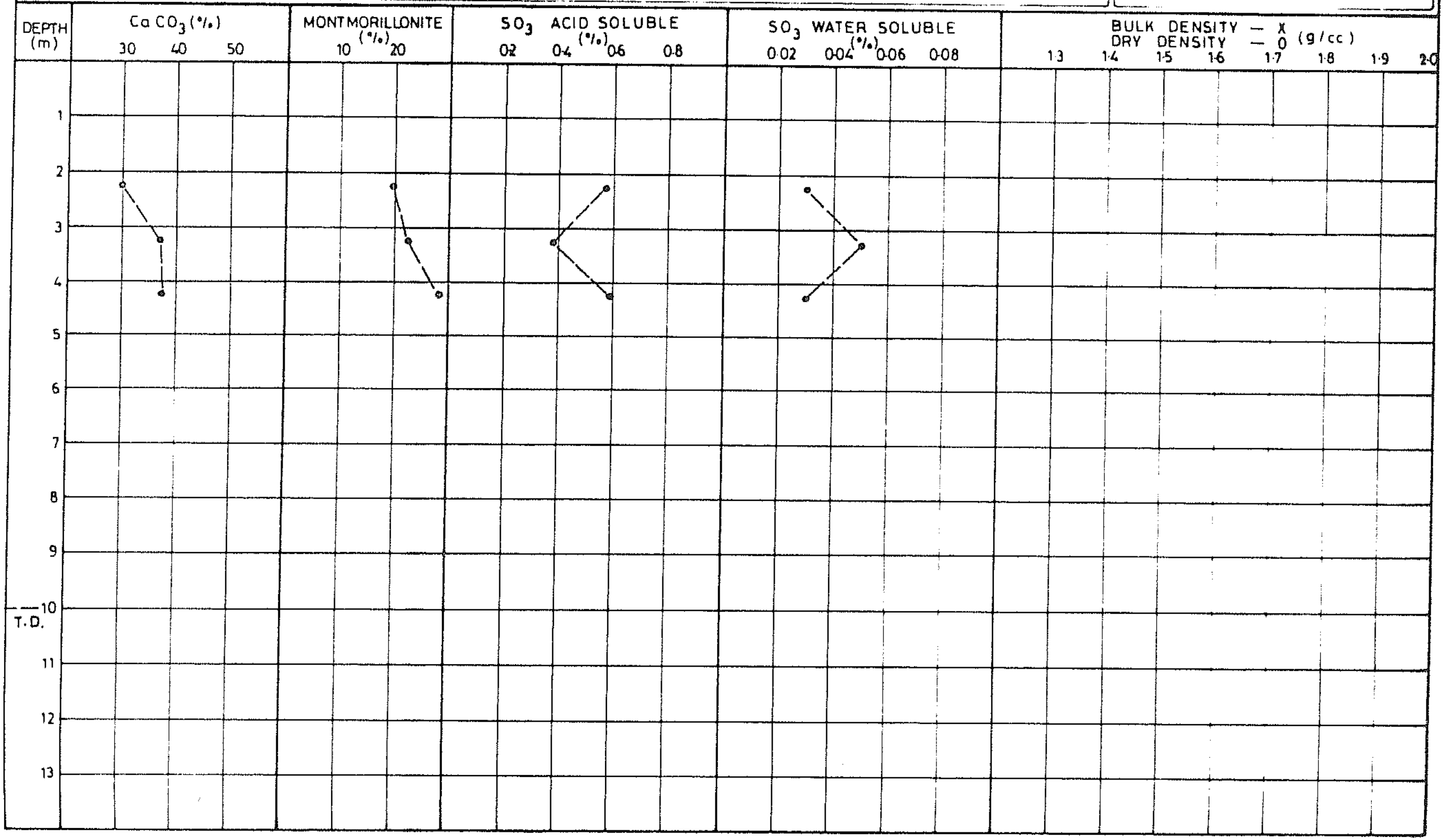
NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No. EG 13/82

SITE ANTHOUPOLIS

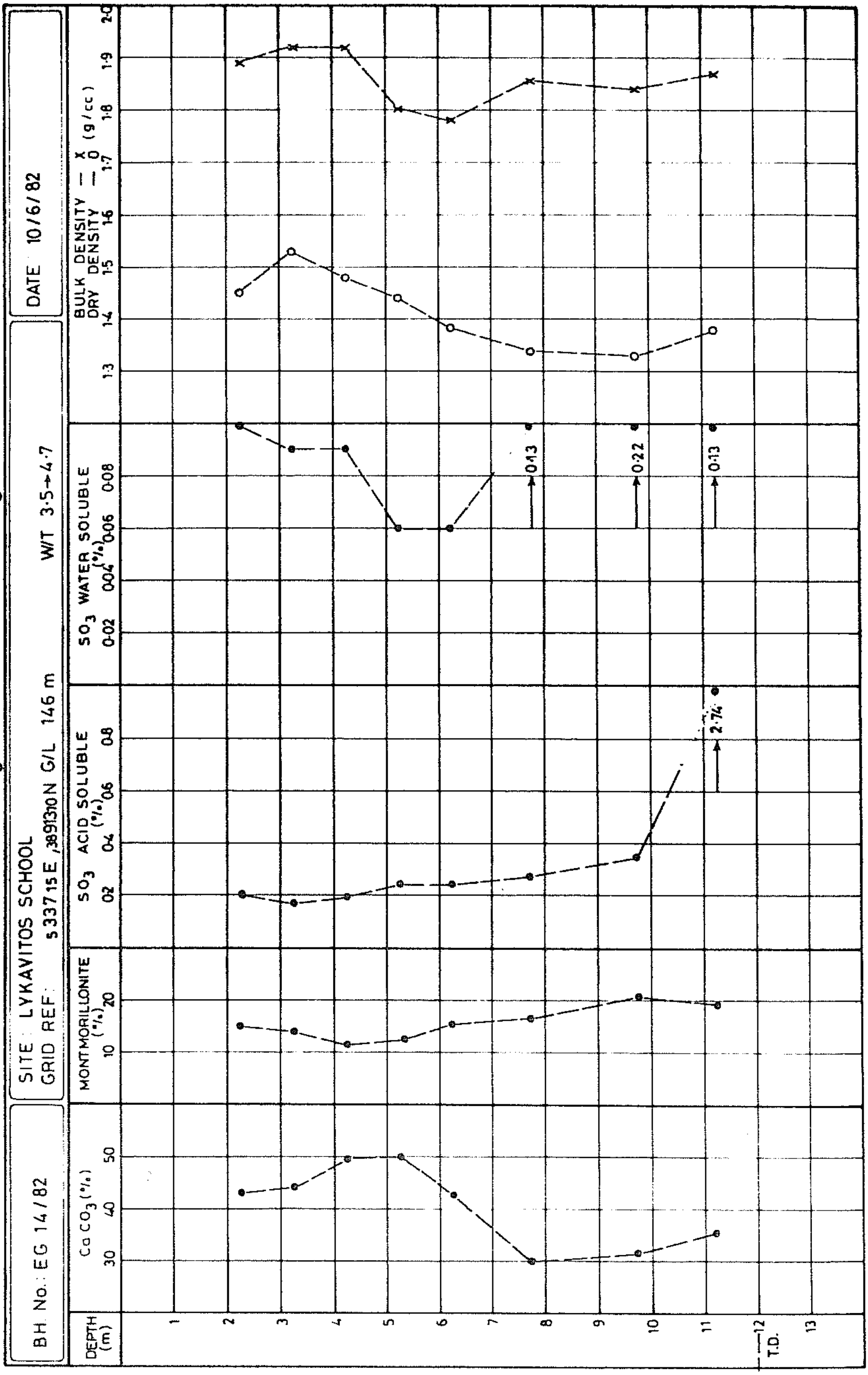
GRID REF: 5 26118 E , 38 86115 N G/L 248 m W/T DRY

DATE 7/6/82



APP. 2.1

NICOSIA COHESIVE SOILS : Variation of Ca CO$_3$, MONTMORILLONITE, SO$_3$, BULK AND DRY DENSITIES WITH DEPTH

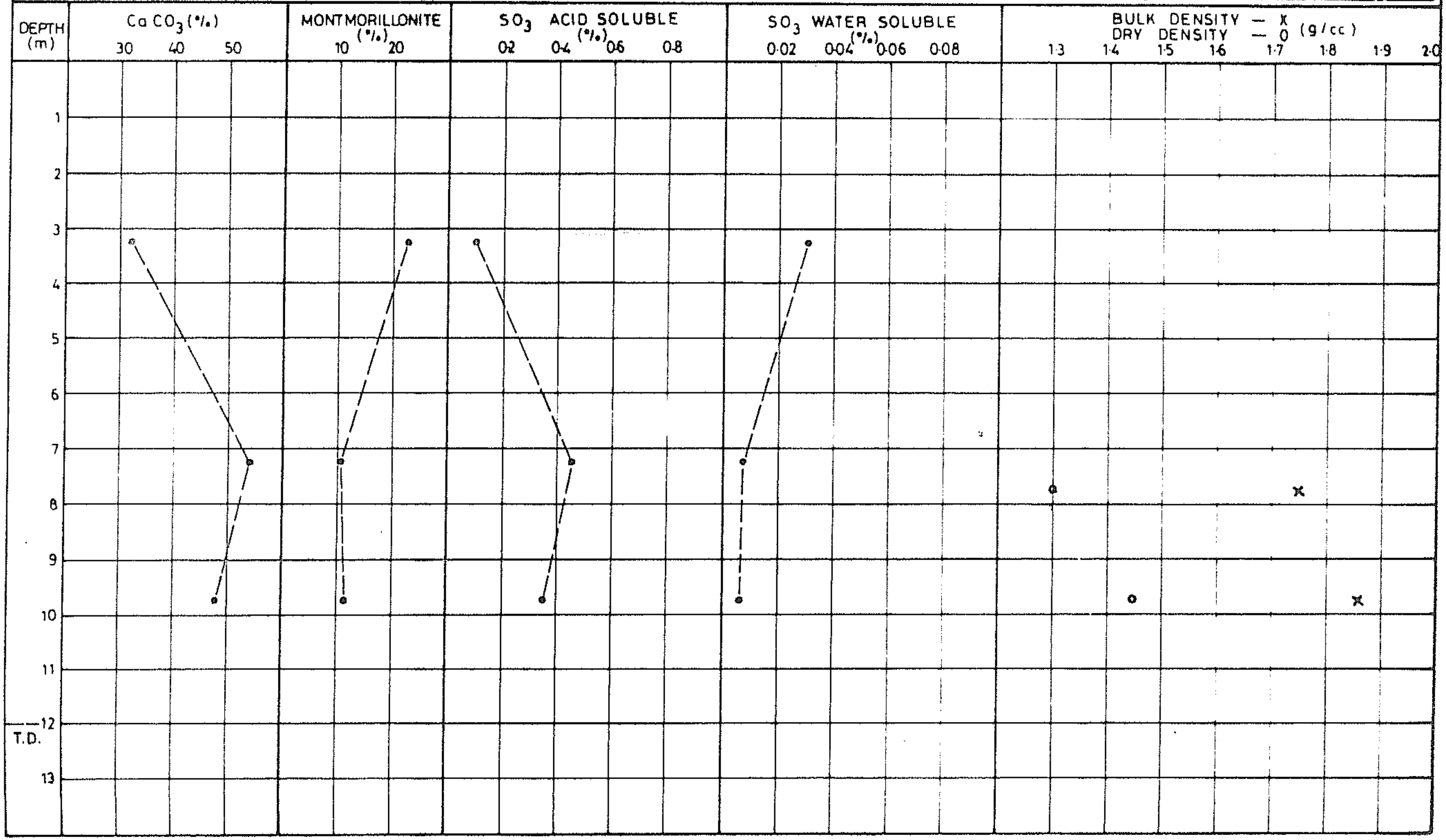


NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH. No.: EG 15/82

SITE: PRODUCTIVITY CENTRE
GRID REF: 534305 E, 3890845 N G/L 159 m W/T 5·30 m

DATE 17/6/82



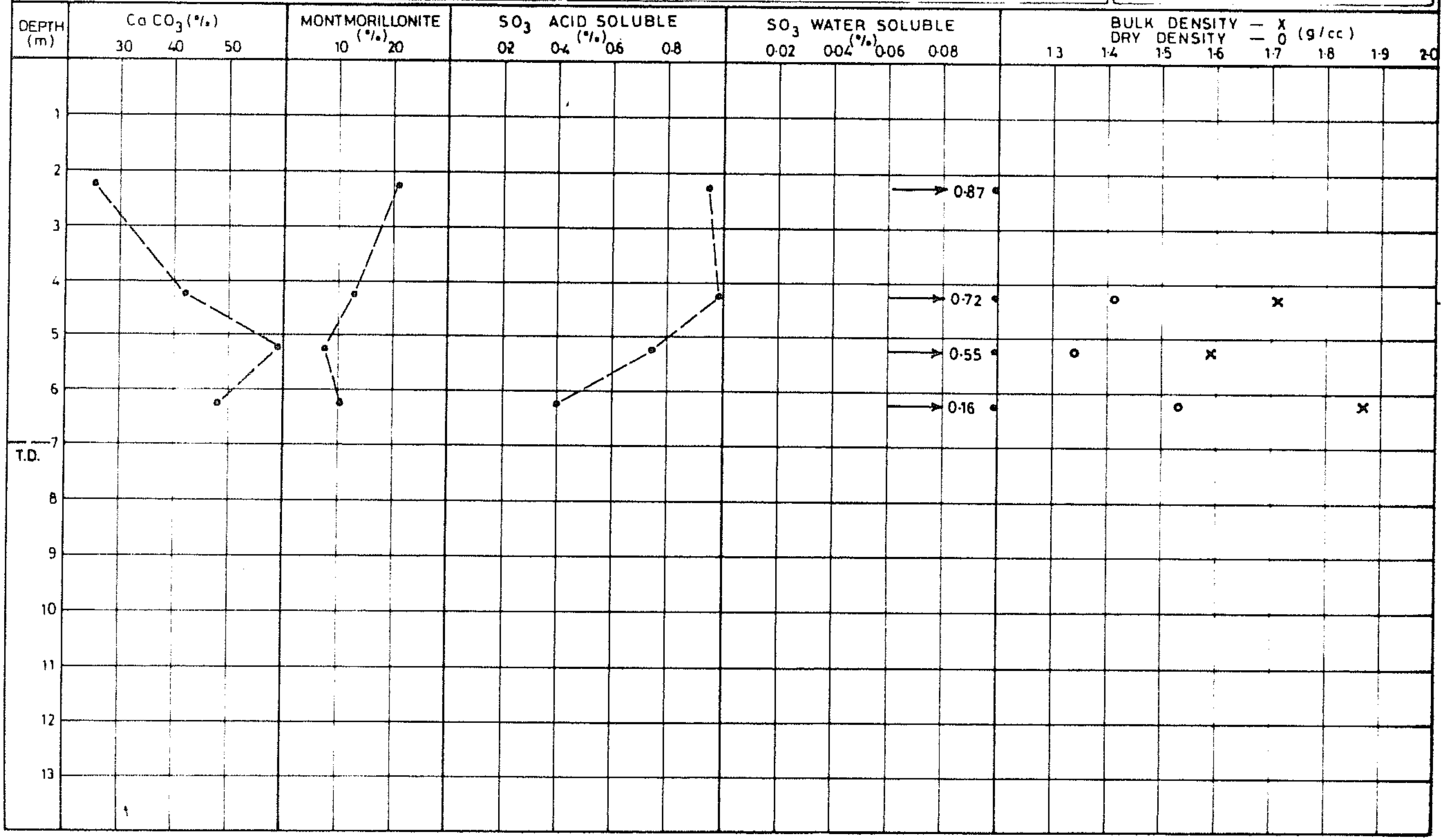
APP. 2,1

NICOSIA COHESIVE SOILS : Variation of $CaCO_3$, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No EG 16/82

SITE EYLENJA
GRID REF: 535830E,3890443 N G/L 138 m W/T DRY

DATE 24/6/82



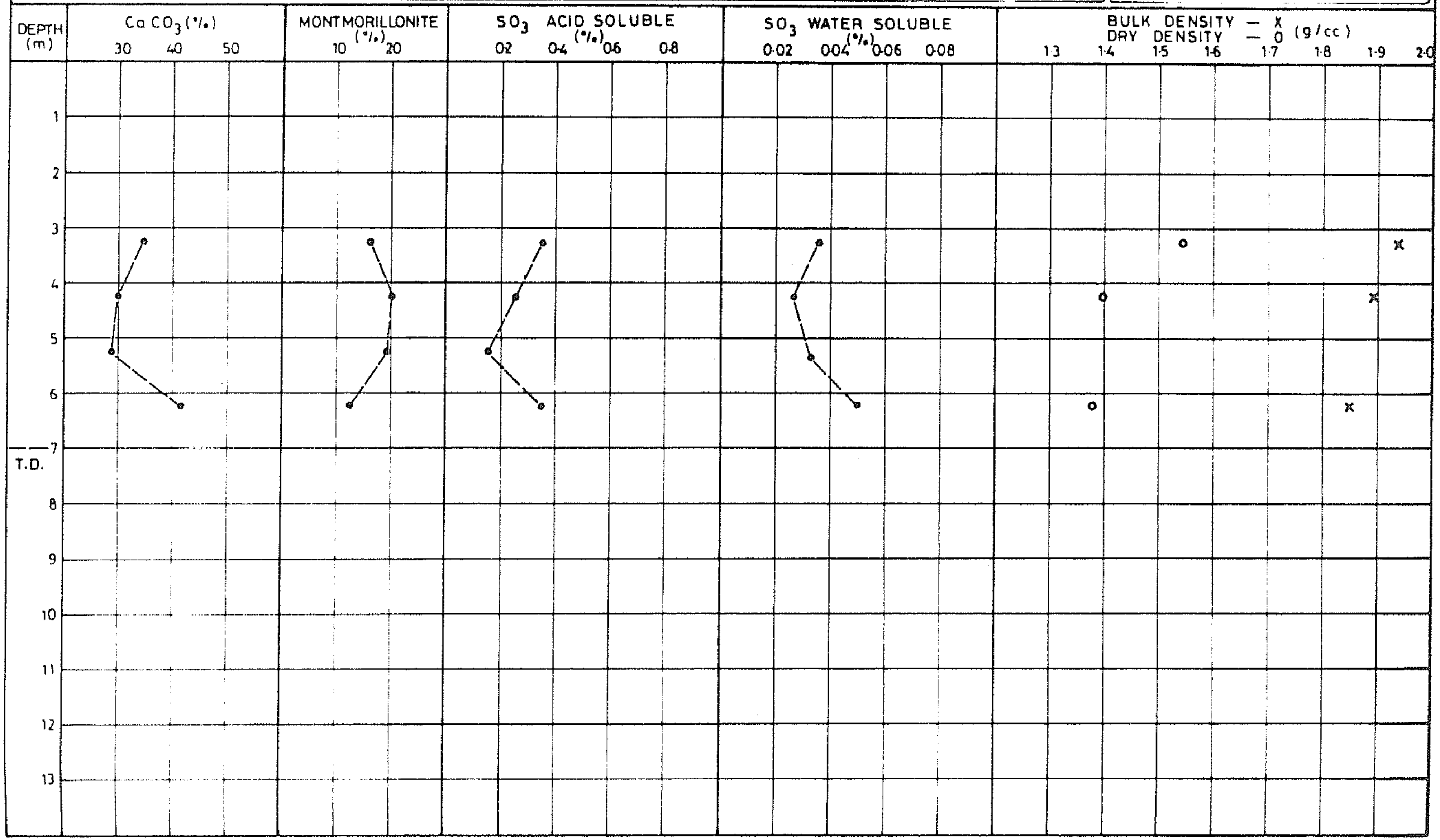
APP. 2.1

NICOSIA COHESIVE SOILS : Variation of $CaCO_3$, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No. EG 17/82

SITE AYIOS NICOLAOS
GRID REF: s 35507 E, 3892870 N G/L 126 m W/T 1·4→1·7 m

DATE 29/6/82



APP. 2.1

PARTICLE SIZE DISTRIBUTION

Site: MAKEDONITISSA

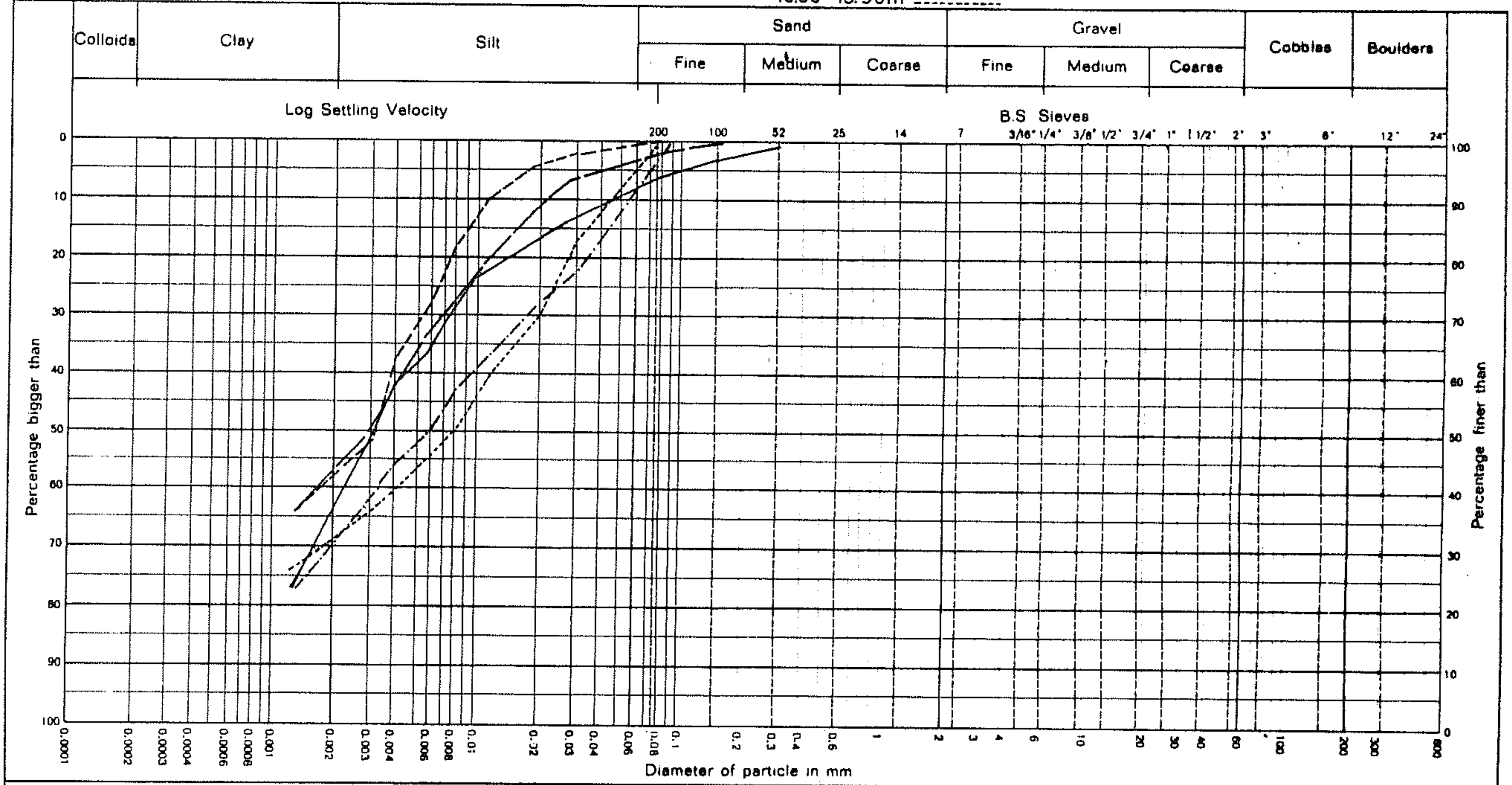
B.H. No.: EG./7/82

Date: 20/10/82

Operator: K. Solomis
A. Petrou

Depth: 2.00-2.50 m ________
4.00-4.50 m ___ ___
6.00-6.50 m _ _ _ _ _
11.00-11.50m _ . _ . _
13.00-13.50m ....

Description:



Note: According to British Standard

Lab. No.

G.S.D. (D.S.) 36

PARTICLE SIZE DISTRIBUTION

Site: EKTHESI

B.H. No.: EG/8/82

Depth 2.00 - 2.50 m ————

3.00 - 3.50 m – – – – –

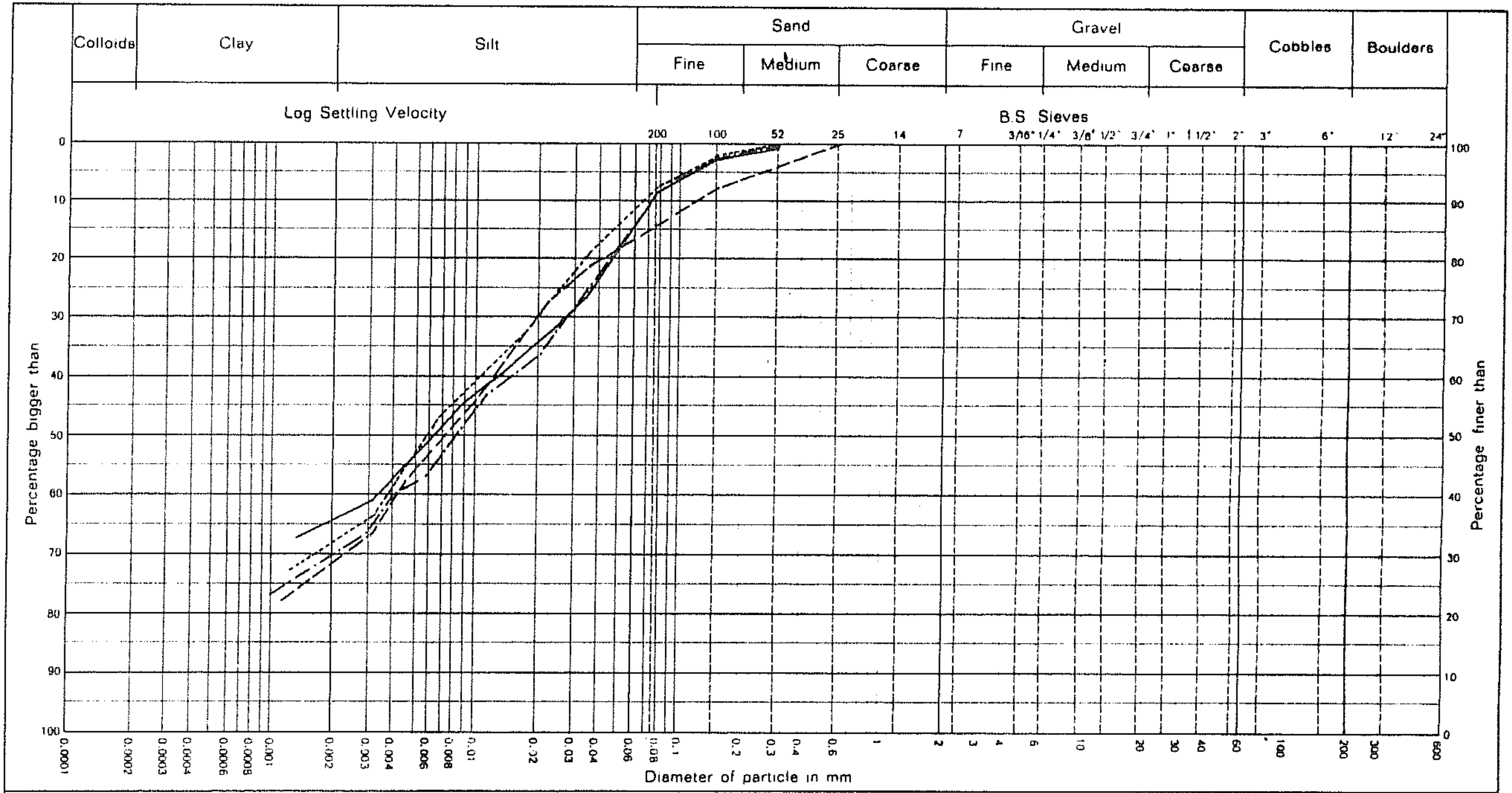
4.00 - 4.50 m —·—·—

5.00 - 5.50 m - - - - - - -

Date: 11/2/83

Operator: K. Solomis
A. Petrou

Description:



Note: According to British Standard

Lab. No.

GSD (DS) 36

APP. 2.2

PARTICLE SIZE DISTRIBUTION

Site: ANTHOUPOLIS

B.H. No.: EG/9/82

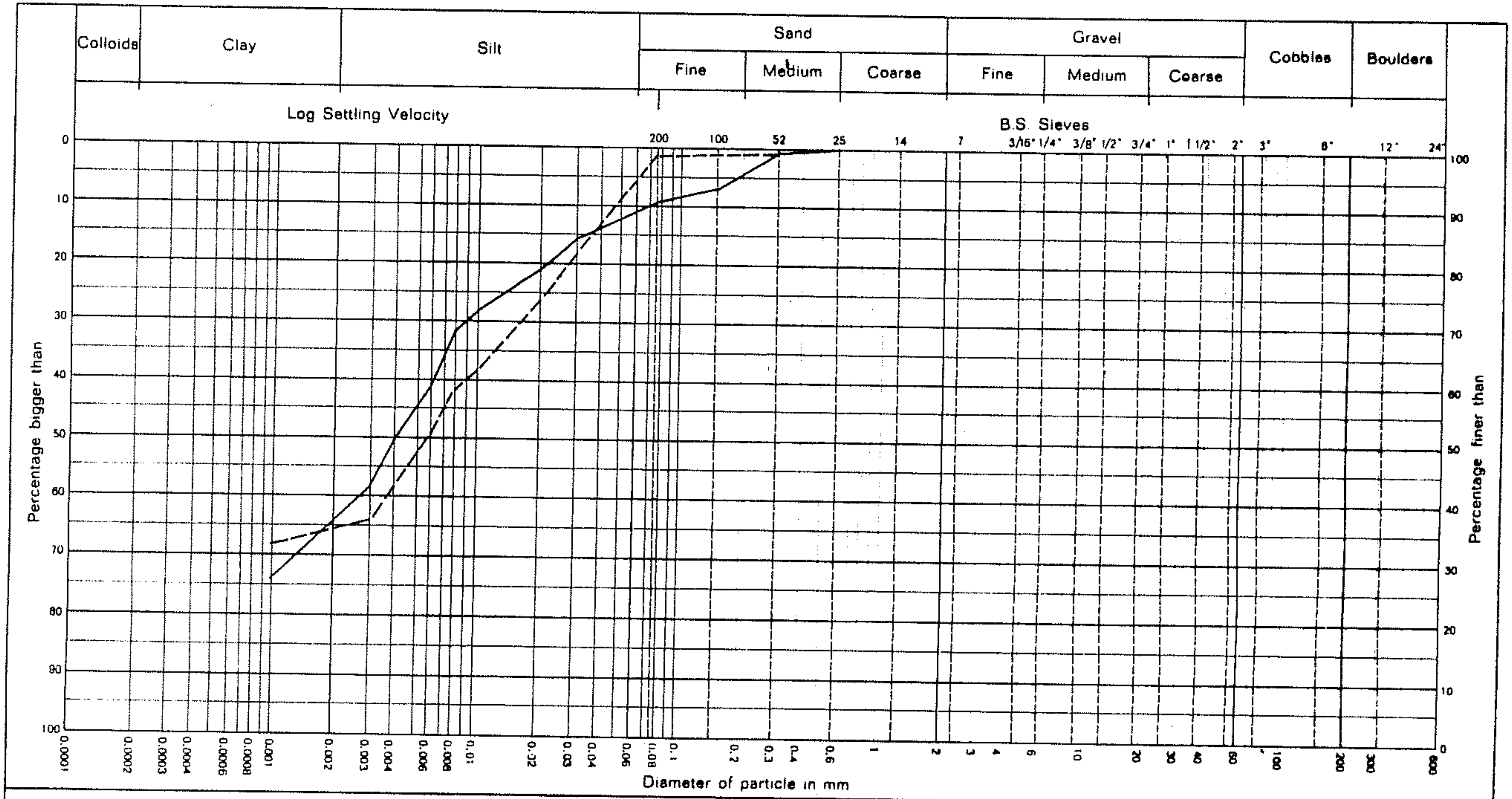
Depth: 2.00-2.50m ———

3.50-4.00m – – – –

Date: 8/2/83

Operator K. Solomis
A. Petrou

Description:



Note: According to British Standard

Lab. No.

G.S.D. (D.S.) 36

fissures may be the effect of reducing conditions on the brown marl in-situ as a result of water-logged conditions during say a pluvial cycle; this is analogous is "gleying" (Bunting, 1965) and may represent a secondary stage of weathering post-dating the formation of the brown marl. Alternatively, a movement of grey clay into open fissures may have occurred as redeposition following a period of drying. Indeed the "light grey clay" has been shown to have significantly higher liquid limits and % clay contents than the surrounding marl.

b) The concentric banding seen in boreholes EG 19/83 and EG 20/83 (see Appendix 1.1.) is probably due to a diffusion front emanating from major fissures and permeating the unfissured "blocks" of marl. These bands are known as Liesegang rings and are seen as a subtle orangey discolouration of the brown marl. This diffusion appears to take place principally in a horizontal direction. The boundary between the grey marl and the brown marl is seen in few exposures. It appears to run parallel to the ground surface (as seen in road cuttings on the new Limassol road) and is a relatively sharp boundary with perhaps 1 to 2m of slightly mixed or mottled material. Fig. 3 shows a cut at the brown/grey boundary at Eylenja: fissures containing crystalline gypsum run along the boundary and connect with the predominant vertical fissure system above. Movement of ground water along these sub-horizontal fissures is clearly seen. The grey marl, even close to the boundary, appears to be massive with few fissures. All fissures appear to contain black manganese oxide staining but not all fissures are associated with the light grey clay. This clay is more plastic than the light grey, slightly sandy, thin laminations associated with the "veins".

5.2. Discontinuities

The reason for the presence of dominantly vertical fissuring in the brown marl is not wholly clear. As a clay approaches the ground, owing to erosion and associated uplift, the applied stress acting downwards decreases. This stress release allows the clay to expand under the influence of recoverable strain energy (Bjerrum, 1967) causing moisture to be drawn into the clay fabric (e.g. Skempton, 1961). Tensile failure during the shrinkage will produce vertical cracks sometimes to considerable depths. Also shear failure may be produced in a shrinking mass where the minor principal stress in the horizontal direction becomes negative, (Williams & Jennings, 1977). Alternatively, passive shear failure may occur due to erosion and a decrease of the vertical stress (Skempton, 1961). The small scale of the shear displacements found is inconclusive. The existence of previous shear displacements becomes significant when the shear strength along a discontinuity is vital to the stability of a foundation on a slope or a landslip. The amount of shear determines to what extent the shear strength has dropped to its residual value for that material (Skempton, 1974). The limited evidence in the Nicosia area for landslipping or cutting failure in the marls makes it difficult to ascertain the role of the discontinuities in any hypothetical stability problems.

An example of instability is found at the Ayios Nicolaos Clinic in the Lykavitos are a of Nicosia (G.R. 917340) where severe damage of a single storey structure includes lateral and diagonal shearing of columns and walls throughout the building. It appears that the spur of brown marl on which the hospital is sited has recently moved laterally by as much as 0.5m. The slope is steep (approx. 60°) but there is no evidence of landslip activity at the present time. It is possible, of course, that remedial measures, including a massive concrete retaining wall and drainage, have removed any evidence of slipping.

No sub-surface investigations have been made as far as the authors are aware. It is possible that the clinic was partially founded on fill material.

The Nicosia Formation has only been slightly folded. The study area is bisected by a wide syncline with axis running N75W (parallel to the Troodos margin) and about 1 km north of Kato Lakatamia and Laxia (Ducloz, 1964). Bedding on both sides of the syncline varies between 0° and 15° occasionally reaching 20°. Three main joint sets are found aligned approximately NNW, NNE and ENE, the two former being most prominent. Some faults of small displacement are associated with these joints. No evidence is found, however, of large scale faulting. Nevertheless, in the area around the Makharios Stadium (e.g. at Arkhangelos and Makedonitissa) severe small-scale folding and faulting is found (see Fig. 3) in heavily jointed brown marl. This is probably associated with the Ovgos fault zone to the north where the Nicosia marl is faulted against the Middle Miocene Kythrea Flysch. The folding, apparently in an EW direction and fold-induced micro-faulting extends from depth of 4.0m to an unknown depth. An upper band of havara is itself folded in places, as is the overlying calcarenitic marl with f.-m gravel lenses. The disturbance has led to intense fracturing and this combined with the thin bedding has resulted in incompetence and instability of even shallow cuts at least in dry conditions. Slickensiding is seen both on bedding and joint planes. All discontinuities are coated with calcium carbonate and manganese oxide.

5.3. Stress History

Laboratory results from consolidation and index tests point to the fact that the Nicosia marls are overconsolidated, but to what extent is not clear (see section 3.3.4.). Values for O.C.R. range from 3 to 16 (for 20 tests carried out at G.S.D.) with a mean of 8.6. Special high-pressure consolidation tests on samples from borehole EG 20/83 from a depth of 13.0m, carried out at B.G.S. produced O.C.R.'s of 24 and 11.00. The results from these tests (see Fig. 12) cast doubt on the adequacy of the stresses achieved by the conventional oedometer apparatus.

Liquidity indices, which are close to zero, support the conclusion of overconsolidation. The shear strength v depth profiles are not, however, conclusive; they do not exhibit the rapid increase of strength with depth demonstrated by some overconsolidated clays (see Lambe & Whitman, 1978). This is no doubt due to the non-homogeneity and variable cementation of the sediments. Similarly, S.P.T. v depth profiles are inconclusive with regard to stress history.

Geological evidence points to a period of emergence and erosion at the end of the Nicosia Formation deposition and prior to the deposition of the Athalassa and Kakkaristra Formations, but this period of erosion was probably brief (Ducloz, 1964); the depth of material eroded is not indicated. In recent times erosion has taken place quite rapidly, partly as a result of flash-flooding and partly as a result of man's influence in removing the vegetation cover (Everard, 1963).

6. CLASSIFICATION & ENGINEERING BEHAVIOUR

6.1. Classification Systems

A sample 'grouping' table is shown in Fig. 18. This is not intended as a classification but simply groups those samples tested from boreholes EG 7/82 to EG 18.82, according to their plasticity and lithology.
The first stage in dividing the 39 samples tested is by BSCS plasticity rating into four groups: EH; VH; H and I. Secondly, we have a colour/texture/stratigraphy description and finally simple swelling and carbonate content ratings of high, medium and low. It was found during preparation of the Geotechnical Map of Nicosia (Hobbs & Loucaides, 1982) that purely lithological descriptions of marls, made by a variety of people, were often unreliable guides to the geotechnical behaviour of the marls. For example, a sample described as a 'calcarenitic marl' may have a lower carbonate content, lower strength and higher plasticity than another described as 'marl'. This is not to say that the lithological description is wrong; indeed cementation for example is a difficult property to quantify, but that such a description may cover a wide range of geotechnical behaviour, which may overlap that of a different litholigcal group.

The British Soil Classification System (BSCS) for Engineering Purposes (ref: BS 5930, 1981 section 42.3; formerly C.P. 2001) has been utilized here in preference to the American Unified Soil Classification System (USCS - derived from the Casagrande Classification) because of its more detailed subdivision of the high plasticity clays. The BSCS subdivides the USCS group 'CH' into three groups: CH - high plasticity clay, CV - very high plasticity clay and CE - extremely high plasticity clay; the Liquid Limit ranges being CH-50 to 70, CV-70 to 90, CE-greater than 90.

Below the Casagrande A-line (see Fig. 5), the BSCS divisions are MH. MV and ME, equivalent to the clay divisions above. All Nicosia marl samples from boreholes EG 7/82 to EG 18/82 fall within groups CH, CV, CE, MV and ME except for EG 16, 5.0 (a calcarenitic marl) and EG 13, 2.0 (a re-worked soil) both of which are in group CI (intermediate plasticity clays). The BSCS has been used as the primary division of the Nicosia marls in the general sample grouping table shown in Fig. 18.

Fig. 18 SAMPLE GROUPING TABLE

B.S.C.S. PLAS. GROUP	Ei (TANG. MOD.)	SAMPLE DESCRIPTION	B.H. NO.	DEPTH (m)	SWELLING PRESSURE (KPa)	CARBONATE CONTENT
EH		CLAY	9	3.5 - 4.0	?	LOW
		V. DISTURBED LAMIN. KHAKI MARL	16	2.0 - 2.5	?	
	8,100	YELLOW/BROWN MARL WITH GREY CLAY IN FISSURES	17	4.0 - 4.5	HIGH	
	10,000		17	5.0 - 5.5		
			18	3.0 - 3.5		MODERATE
			18	5.0 - 5.5		?
			18	7.5 - 8.0	*	?
VH	4,400	GREY MARL	7	11.0 - 11.5	LOW	LOW
	16,000	REWORKED KHARKI MARL	7	2.0 - 2.5		
		REWORKED RUBBLY CLAY	9	2.0 - 2.5	*	
	20,000	YELLOW/BROWN/KHAKI MARL WITH GREY CLAY IN FISSURES	17	3.0 - 3.5		
			7	6.0 - 6.5	*	
	8,500		8	5.0 - 5.5	MODERATE	
			7	4.0 - 4.5	*	
			14	7.5 - 8.0	HIGH	
	14,000		14	9.5 10.0		
			15	3.0 - 3.5	*	VERY LOW
			14	2.0 - 2.5		MODERATE
			18	4.0 - 4.5	*	
	6,500		18	9.5 - 10.0	*	
	25,000		18	11.0 - 11.5		
H	28,000	GREY MARL	14	11.0 - 11.5	* MODERATE	LOW
	5,000		7	13.0 - 13.5	LOW	
		REWORKED MARL ?	13	3.0 - 3.5		MODERATE
		RED/BROWN MARL (APALOS?)	13	4.0 - 4.5	*	
	22,000	YELLOW/KHAKI MARL	14	3.0 - 3.5	* MODERATE	
	17,500		14	6.0 - 6.5	LOW	
	14,500		14	4.0 - 4.5	*	HIGH
			14	5.0 - 5.5		
	15,000	CALCARENITIC MARLS	15	9.5 - 10.0	*	
	7,500		16	6.0 - 6.5		
	30,000		16	4.0 - 4.5	*	MODERATE
			15	7.5 - 8.0	*	LOW
		YELLOW SANDY MARL WITH GREY CLAY IN FISSURES	8	3.0 - 3.5		
			8	2.0 - 2.5	* MODERATE	
			8	4.0 - 4.5	LOW	MODERATE
	17,500	YELLOW MARL WITH GREY CLAY IN FISSURES	17	6.0 - 6.5	MODERATE	
I		REWORKED SOIL	13	2.0 - 2.5	* LOW	LOW
	25,000	MARLY CALCARENITE	16	5.0 - 5.5	LOW	VERY HIGH

BSCS GROUP	L.L.
EH	> 90
VH	70 → 90
H	50 → 70
I	35 → 50

SWELLING PRESSURE (KPa)	
LOW	< 20
MODERATE	20 → 35
HIGH	> 35

CARBONATE	%
VERY LOW	< 25
LOW	25 → 35
MODERATE	35 → 45
HIGH	45 → 55
VERY HIGH	> 55

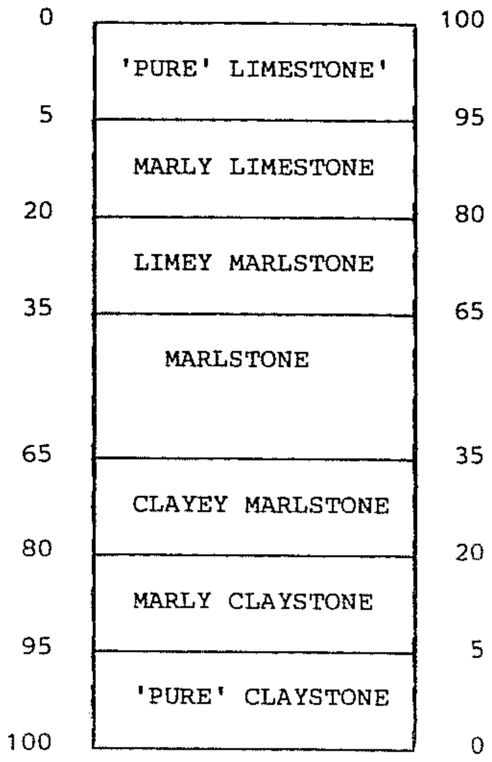
(* Estimates based on index and mineralogical data)

Fig. 18

Sub division of soils on the basis of grain size distribution is incorporated in both BSCS and USCS but only for the coarser materials. A petrological grain-size classification, based on a ternary clay/silt/sand diagram (Folk, 1974) is shown in Fig. 16. The marls are concentrated in a small triangle on the silt side of the 'mud' and 'sandy mud' units. Samples rich in carbonates tend to lie to the 'silt' or 'sand' side of the marl triangle. Samples (three in number) of grey marl lie to the silt side of the triangle.

The grading curves themselves (see App. 2.2.) show that the carbonate-rich marls tend to have medium to coarse silt as their main constituent. A plot of montmorillonite content v % clay (Fig. 17) shows that, in general, carbonate-rich marls have a low %montmorillonite/%clay ratio for %clay < 37. Thus it would appear that some part of the carbonate is clay-sized but the majority is silt-sized.

A simple classification for marls proposed by Fookes and Higginbottom (1975) is shown below:



If this is now incorporated in an empirical ternary diagram of clay/carbonate/quartz etc. (see Fig. 16) the basis of a marl classification is formed. The classification includes the sub-divisions marl (M), sandy marl (SM), calcarenitic marl (CM), marly calcarenite (MC) and Havara (H)*. Little data, other than that from boreholes EG 7/82 to EG 18.82 is available with both carbonate and clay fraction results. Thus further available with both carbonate and clay fraction results. Thus further data may dictate modifications, hopefully of a minor nature, to this ternary classification (see Fig. 16). Clearly carbonate content, clay fraction (and montmorillonite content) are key properties determining the behaviour of the marl.

6.2. Engineering Behaviour

6.2.1. General

The engineering behaviour of the Nicosia Marls is summarised in the table shown in Fig. 19. This is not intended as a basis for design calculations but simply as a summary of the geotechnical behaviour of the marl known to date and as a guide to the likely range of engineering behaviour. This table necessarily describes different types of marl in isolation and does not account for vertical successions of different marl types or marls with other rock types, such as calcarenites or gravels. In fact it is unusual to encounter a uniform marl (M) at shallow depth which does not contain lenses or bands of calcarenitic marl (CM) marly calcarenite (MC), calcarenite, havara (H)* or gravel. The marl (M) is however, the one component of such a mixed succession which is most susceptible to plastic deformation, swelling and shrinkage. The other problem in classifying shallow marl is the presence of highly variable 'reworked' material whose engineering behaviour may differ significantly from that of the underlying 'undisturbed' material. Marl naturally reworked by, for example, slope movement (colluvium) is, however, generally looser and more variable than the former. It has been found that shallow samples (3m depth) behave less predictably than deeper samples, due to the seasonal wetting and drying consequent breakdown of the fabric, and to the variable influence of farming, vegetation and topsoil genesis generally.

---

* A deposit of almost pure calcium carbonate, produced by the leaching process.

Fig. 19 TABLE OF LIKELY ENGINEERING BEHAVIOUR

MARL TYPE (based on classif. in fig. 16)	B.S.C.S. PLASTICITY CLASSIF.	CONSISTENCY/ STRENGTH CLASSIF. (C.P. 2004)	GRADING/ PERMEABILITY	SWELL/ * SHRINK POTENTIAL	COMPRESSIBILITY WHEN SATURATED	SHALLOW FOUNDATIONS	EXCAVATION/ FILL/CONCRETE ATTACK Etc.
MARL	EH	Firm to very stiff (or hard) depending on degree of cementation & overconsolidation; fresh marl may be up to 30% stronger than weathered marl.	Clay & fine silt/ poor drainage but modified by weathering/perm. is low.	High	Moderate at pressures up to 500 kPa.Low above 500.	Good foundation/ Bearing pressures <200 kPa should be founded at depth >4m/Excavations should be protected from moisture variation and supported if >4m deep.	Fresh marl may contain sufficient insoluble sulphates to cause concrete attack. Weathered marl is relatively free of insoluble sulphates but may contain pockets of gypsum/generally poor fill material partic. EH and VH.
	VH		AS ABOVE	Moderate to high	Low to moderate at pressures up to 200 kPa,Low above 200.		
	H		Med. to coarse silt/drainage is moder. poor/ perm. is low.	Low to moderate	Low		
SANDY MARL	H I	Soft to v.stiff ø higher than for 'marl'.(SPT tends to be high)	Well-graded, Med. to coarse silt/ perm is low/ drainage is poor	Low to moderate	Probably low	Good foundation. May contain soft lenses or bands.	As for marl. Dry slopes may suffer progressive collapse.Moderately good fill material.
HAVERIZED MARL	H I	Soft to v.stiff depending on degree of cementation	F.Sand, silt and clay. Drainage moder.	Very low to low (?)	May be highly compressible	Unreliable foundtn. May be removed if thin layer.	May suffer soln. and leaching/poor fill material.
CALCARENITIC MARL	H	Firm to v. stiff.	Moder. well graded med.→coarse silt & f. sand. Permeab. is low. Drainage is poor.	Low	Moderate at pressures up to 500 kPa. Low above 500.	As for marl	As for marl/moderately good fill material.
MARLY CALCARENITE	I CL	Firm to v.stiff.	Moder. poorly graded.Fine sand, coarse silt.Permeab. is low.Drainage is poor.	Low	Variable with cementation. Probably low to very low.	V. good foundtn. but may contain voids or bands of softer marl.	Excavation may be difficult, esp. with bands of calcarenite present. Good fill material.
REWORKED MARL (Incl. colluvium)	Variable	V. variable/generally firm.Possib. shear planes parallel to ground.	V. variable. May contain sands & gravels and voids. Drainage poor→moder. good.	Low	Variable. May be highly compr.	Poor foundation due to variability. May contain planes of weakness, partic. on slopes.	Excavation may result in instability partic. when wet.

* swell/shrink potential may be reduced by concentrations of iron salts and calcites

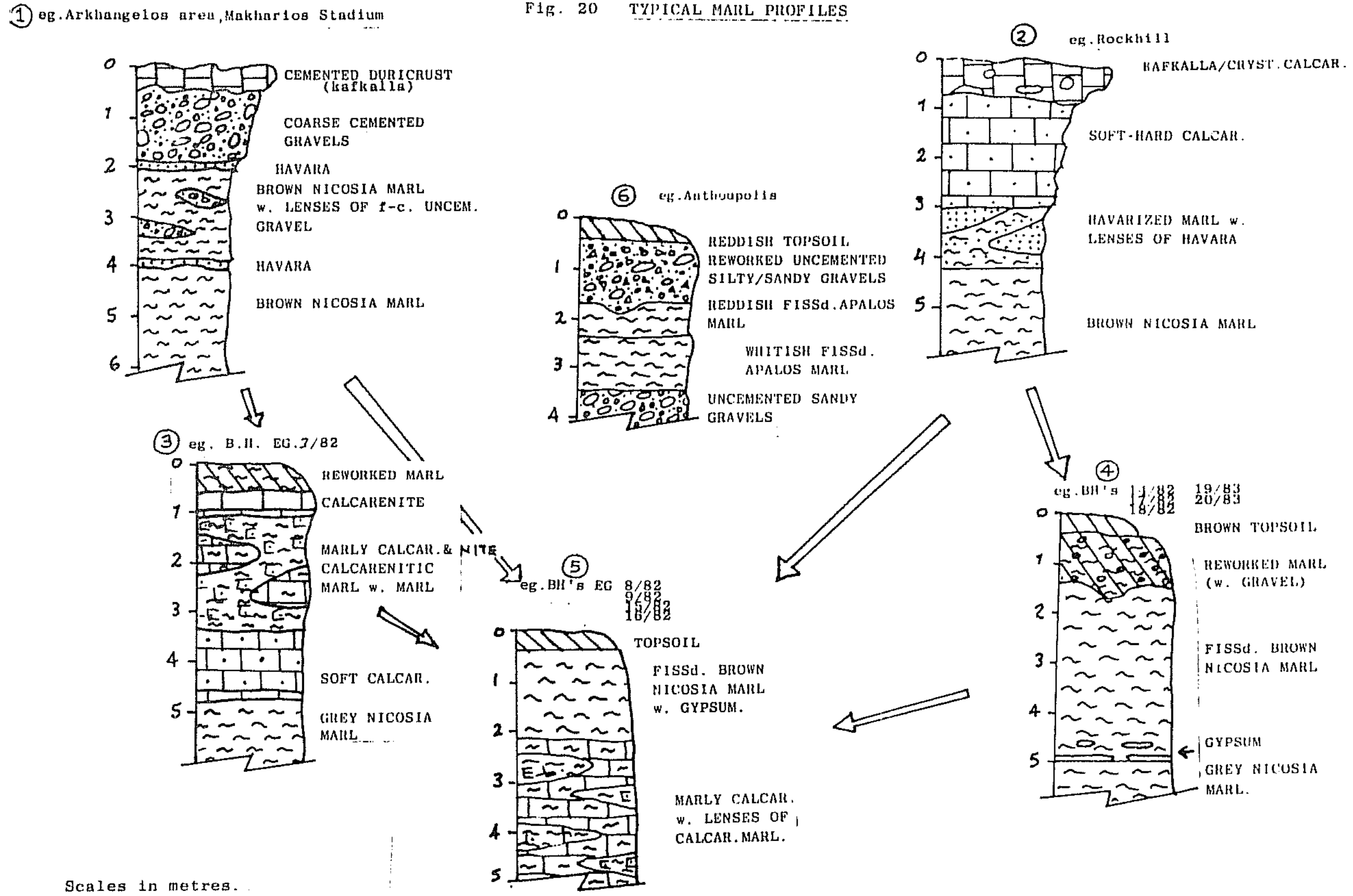
In borehole EG 19/83 an incompetent rubbly, reddish-coloured marly soil was encountered to a depth of 5.0m. This material was too loose and variable to sample and test successfully, but nevertheless represents a foundation hazard at this site.

Fig. 20 shows the range of shallow soil profiles involving marl encountered in the greater Nicosia are in simplified diagrammatic form. Six types of marl profile are identified (i.e. profiles with marl as a major component). Profiles 1 and 2 are found on hill-tops and profiles 3 and 4 are found at midslope and at valley-bottom. Examples from which the profiles were constructed are quoted in Fig. 20, as well as their equivalent profile or stratification code used for the Nicosia Geotechnical map (see Hobbs & Loucaides 1982). Bearing capacity analyses of stratified soils are confined to either approximate solutions for simple two layer purely cohesive cases or complex finite-element solutions for three or more layer cases where ideal elastic behaviour is assumed for each layer. (Poulos & David, 1974; Feda, 1978).

6.2.2. Bearing Capacity

Fig. 21.2 (a) shows the ideal homogeneous, or one layer case, Boussinesq pressure 'bulb' or iso-stress contour, (Fig. 21.2 (b)) such as might obtain in profile 4 (Fig. 20). Fig 21.2 (b) shows the pressure bulb for an upper layer half the foundation diameter in thickness and with a Youngs Modulus of Elasticity ten times that of the underlying soil, as for example in profiles 1, 2, and 3 in Fig. 20. These layers are then reversed in Fig. 21.2 (c) as for example in profiles 5 or 6 in Fig. 20. From the diagrams it can be seen that in case (b) (Fig. 21.2), the stress in the lower layer is reduced significantly compared to case (a) (Perloff & Baron, 1976), but the area over which this reduced stress acts is greater (Leonards, 1962). conversely in case (c) (Fig. 21.2) the stress in the lower layer in increased compared to case (a). If the thickness of the upper layer is greater than approximately five times the radius of the foundation, the stress taken by the lower may be considered neglible whatever the value of E_1/E_2. If, however, the thickness of the upper layer is less than approximately half the foundation radius and the E_1/E_2 ratio is high (for example a thin duricrust on marl) nearly all the stress is taken by the weaker lower layer and the crust may fail by punching through

Fig. 20 TYPICAL MARL PROFILES



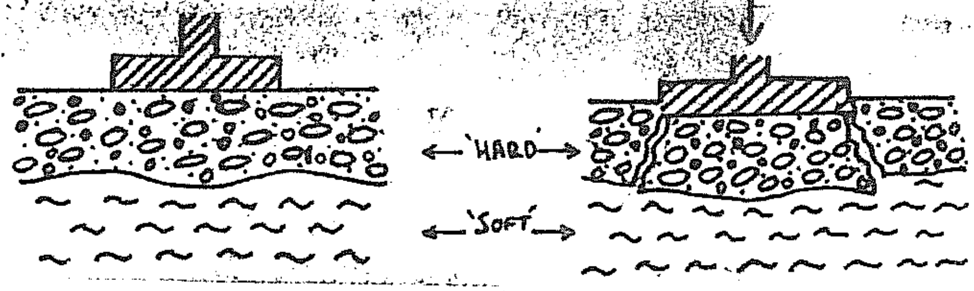


Fig. 21.1 PUNCH-THROUGH FAILURE

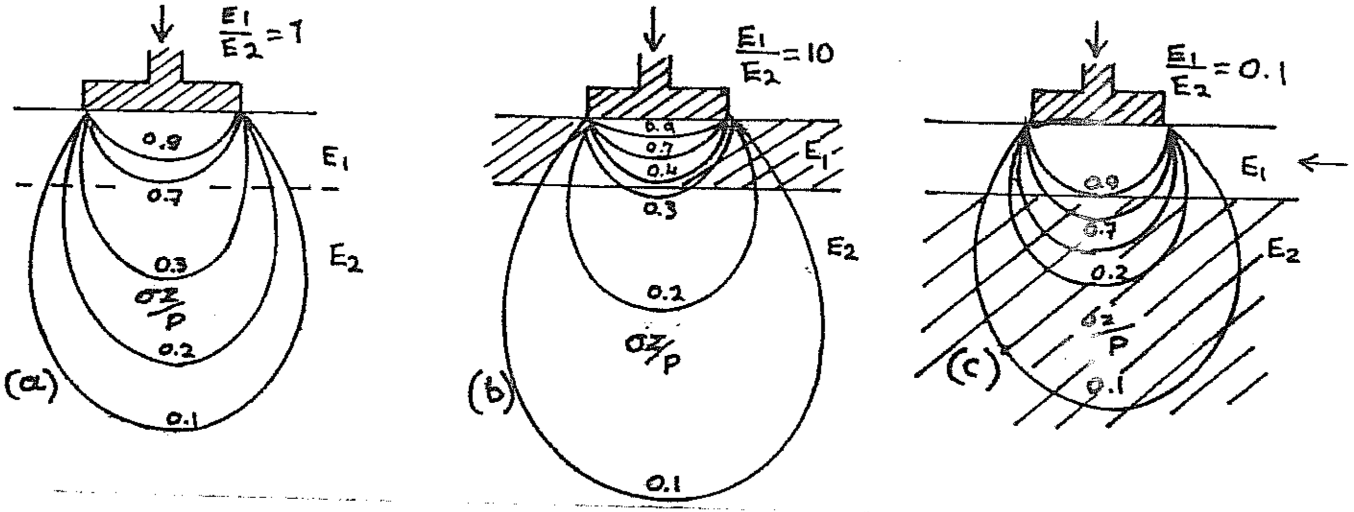


Fig. 21.2 BEARING PRESSURE CONTOURS BELOW A CIRCULAR FOUNDATION IN A 2-LAYER DEPOSIT (Ref:Poulos & David, 1974)

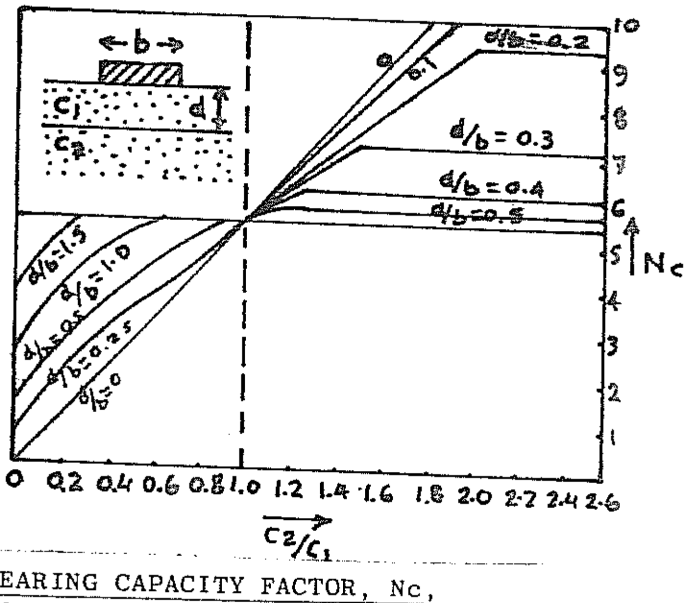


Fig. 21.3 BEARING CAPACITY FACTOR, Nc, FOR A 2-LAYER COHESIVE DEPOSIT (Ref: Button, 1953)

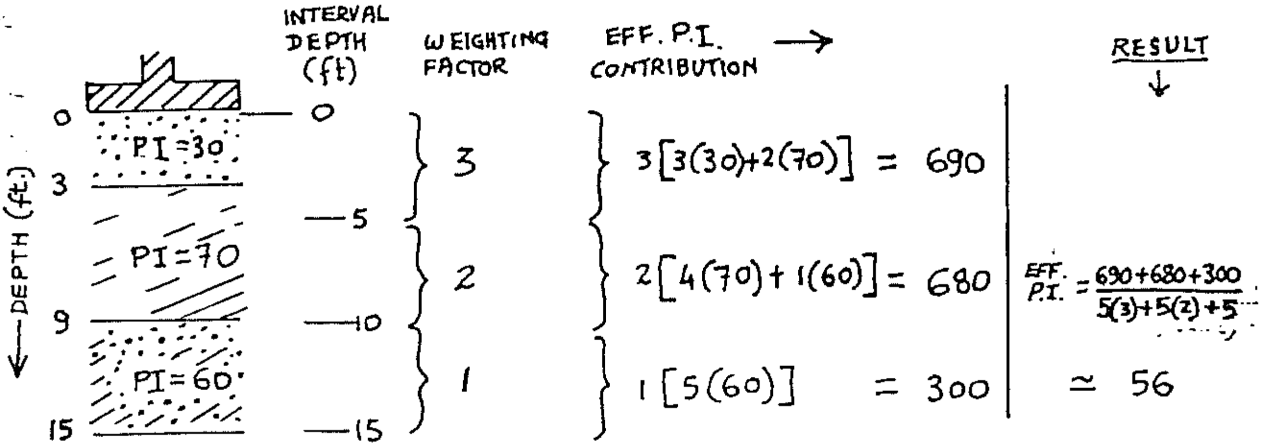


Fig. 22.1 EXPANSIVE POTENTIAL - EXAMPLE (B.R.A.B., 1968)

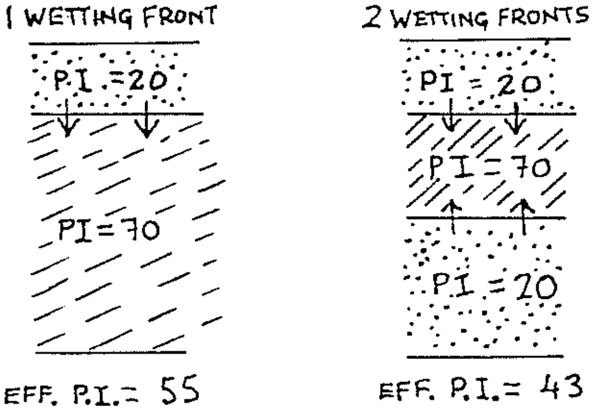
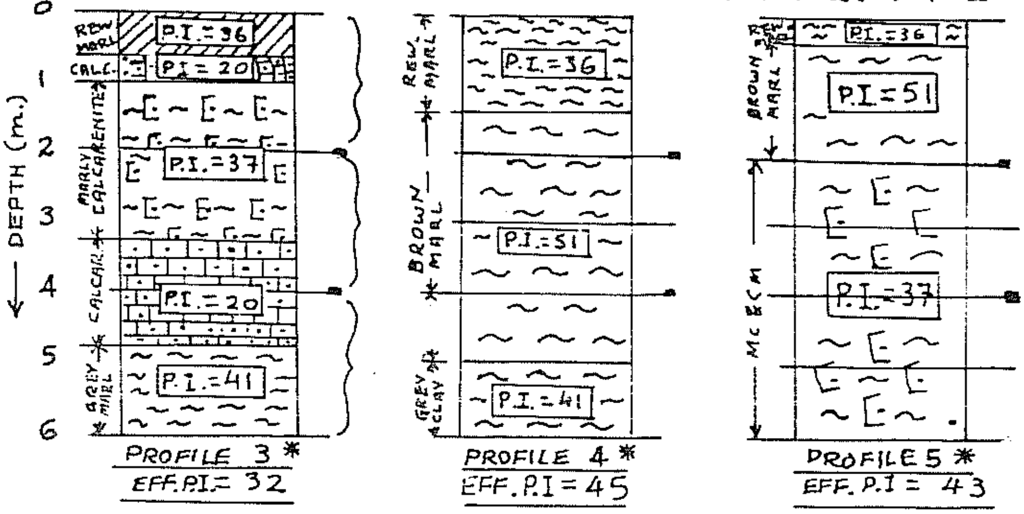


Fig. 22.2 EXPANSIVE POTENTIAL - EXAMPLE (Mathewson and Dobson, 1982)

$$\text{EFFECTIVE P.I.} = \frac{3\sum h_nPI_n + 2\sum h_nPI_n + \sum h_nPI_n}{2(3) + 2(2) + 2}$$



* Profile N^os refer to Fig. 20

Fig. 22.3 EXPANSIVE POTENTIAL - NICOSIA MARL

Fig. 22 EXPANSIVE POTENTIAL OF SOIL PROFILES

Laxia (G.R. 867341). This process may be accelerated by shallow mining within or immediately below the duricrust, for example at Eylenja (G.R. 902365). The hazard to buildings on the duricrust close to its edge is obvious. Thick deposits of calcarenite often contain bands of weaker, fissured marl, which, if subject to rapid erosion, may reduce the competence of the rock mass as a whole.

Evidence for instability of man-made cuts in marl is confined to two types: firstly, gradual cutting-back of dry vertical slopes in fissured marl (particularly Apalos marl) is seen to occur as a result of fissures and shrinkage cracks which reduces the exposed marl mass to what is effectively a coarse granular material which fails retrogressively building up a scree at its foot (see fig. 3). Secondly, surface run-off during heavy rain may be channelled down open joints and fissures which emerge in a cut face; the water scouring fine or loose material from around the discontinuity to result in isolation and finally slump or toppling failure of what has become a free-standing block of marl. This is prevalent in built-up areas where drains cannot cope with the sudden flow of surface water, the effect of which is magnified by channelling along ditches, culverts, tarmac etc., and is noticeable within the uppermost reworked or colluvial marl and fill. A failure of this latter type was observed by the authors during heavy rain in the walls of a 6m deep basement excavation near the site of borehole EG20/82.

6.2.5. Compaction

Little information on the compaction of Nicosia marls is available for the authors at present. However, Anon, (1972) include five modified Proctor tests in their report on the Makarios stadium site investigation. The tests were carried out on admixtures of marl and sand obtained from trial pits throughout the pits depth. The coarser and less plastic admixtures gave notably higher maximum dry unit weights (1.90 g/cm^3) and lower optimum moisture contents (14%) than the finer grained, more plastic admixtures which gave $\gamma d = 1.70$ g/cm^3 and m = 20%. The most favourable results came from a sample with a gravel content of 40%. Marl which is not mixed with coarse material may be expected to give a maximum dry density in the range 1.4. to 1.6 g/cm^3; i.e. generally poor for most purposes.

CONCLUSIONS

A wide range of geotechnical, mineralogical and geotechnical tests have been applied to marls from the Nicosia area. The results, which have been analysed and cross-correlated in some detail, show that the marl is a strong, plastic, carbonate-rich montmorillonitic, cemented and over-consolidated silty clay of moderate compressibility. A summary of the engineering behaviour of the various subdivisions of the marl is given in Fig. 19. The behaviour of the marl is closely related to moisture content, carbonate content, cementing, clay fraction and montmorillonite content, all of which are variable with both location and depth. The relative proportions of carbonate and montmorillonite are a key factor, as is the contribution of the carbonate content to cementing and hence possibly high strength-sensitivity. The particle-size grading of the marl is dependent upon the state of weathering and the carbonate content. More important, however, may be the particle-shape. It has been indicated (Ducloz, 1964) that a high proportion of non-clay mineral grains are angular as a result of very rapid erosion and deposition. This fact alone may have an important influence on the geotechnical properties including Atterburg limits and the strength. In fact the relatively high residual strength obtained may be a direct result of the angular nature of the silt fraction. A further consideration is the likelihood of aggregations of clay size particles into silt-sized 'peds', and their effect on the geotechnical properties. Detailed study of the test samples using a scanning electron microscope may prove to be most valuable in this respect.

Mineralogically there is little variation within the samples tested and a common origin is almost certain. Chemical tests did reveal, however, high total sulphate levels within the 'grey' marl samples, though only three were tested. The depth of the 'active zone', i.e. the depth to which seasonal water content variation takes place, is an important consideration. This may vary 3 m to 8 m depending on location and lithology. The discontinuity regime and hence the mass properties of the active zone material differs from that of the marl below. S.P.T. values are usually higher within the active zone for most of the year probably as a result of the cementation. A good relationship has been established between moisture content and log swelling pressure (see Fig. 15); a moisture content drop from 40% to 30% causing a tenfold increase in swelling pressure. This explains the damage due to heave experienced with many shallow (i.e. within the active zone) lightly-loaded foundations. Protection of the excavation, both before and after construction, from water content variation is thus seen to be critical. An attempt has been made to classify the marls according to carbonate and clay fraction (see Fig. 16). This appears to be a useful method but may require modification of the areas designated for calcarenitic marl and marly calcarenite, in the light of further testing. The problem encountered when describing or attempting to subdivide the marl is that marl and calcarenite are not mutually exclusive materials, but a smooth and uninterrupted grading from one to another exists with carbonate replacing clay mineral and vice versa. This grading from one to the other may occur laterally and vertically but is not always present. Sharp litholigical and geotechnical boundaries do exist but the materials either side of that boundary may lie anywhere along the marl — calcarenite scale. In fact the clay — carbonate scale is a two leg scale: one being clay — havara (i.e. pure fine-grained carbonate) and the other being clay — calcarenite (i.e. an impure coarse-grained carbonate). Thus a 'havarized marl' may differ from a 'calcarenitic marl' in terms of particle size grading and cementation, though having the same carbonate content. A successful measure of the degree of cementation has not been identified, but sensitivity may be an indirect indicator of cementation.

It is proposed that further studies of the marl include analysis of the microstructure to answer the questions of aggregation and cementation, and thus relate this to the geotechnical behaviour. Other fruitful area of the study include high pressure consolidation tests and ring-shear tests, both of which have produced interesting results which may prove characteristic of the marls. Finally it would clearly be a great advantage to be able to monitor the performance of a building and compare it with the theoretical behaviour obtained from the laboratory results. Alternatively, a test site may be found where seasonal moisture variation and volume change could be monitored at various depths within the active zone profile, along with small scale site loading tests.

BIBLIOGRAPHY

ANON (1972)
Report on site investigation at Makarios Stadium, Nicosia.
Messrs. Kotzias & Stamatopoulos, Athens, Greece.

ANON (1963)
Report on site investigation at Larnaca Road, Nicosia for Messrs. Raglan Squires & Partners, by the Cementation Co. Rep. No. 3629/MD $M^{c}Q$.

BARDEN L. (1972)
"The relation of soil structure to the engineering geology of clay soil".
Q.J.E.G. London, 5, pp. 85 - 102.

BAROZ & BIZON (1974)
"Le neogene de la chaine du Pentadaktylos et de la partie nord de la Mesaoria (chypre)".
Rev. de l'Ins. France du Petrol., Paris Mai-Juin, 1974 Vol. XXIX No. 3.

BEAR L.M. (1960)
"The Geology and Mineral Resources of the Akaki-Lythrodonda Area"
Geol. Mem. Geol. Surv., Cyprus, No. 3.

BJERRUM L. (1967)
"Mechanism of progressive failure in slopes of overconsolidated plastic clays and clay-shales".
J. Soil Mech - and Found. Div., A.S.C.E. Vol 93, pp 1 -49.

BUNTING B.T. (1965)
"The geography of soil".
Hutchinson University Library Publ.

BURLAND J.B., BROMMS B.B., de MELLO V.F.B. (1977)
"Behaviour of foundations and structures - State of the Art Report".
Proc. 9th Int. Conf. S.M.F.E., Tokyo, 2, pp. 495 - 546

BUTTON S.J. (1953)
"The Bearing Capacity of footings on a two-layer cohesive subsoil".
Proc. 3rd Int. Conf. on S.M.F.E., Zurich, Vol 1, p. 332.

CHANDLER R.J. (1969)
"The effect of weathering on the shear strength properties of Keuper marl".
Geotechnique 19, No. 3 pp. 321 -334.

CHAPMAN R.W. (1974)
"Calcareous duricrust in Al Hasa, Saudi Arabia".
Geol. Soc. Am. Bull., V. 85, pp. 119 -130.

CLEINTUAR M.R., KNOX G.J & EALEY P.J. (1977)
"The Geology of Cyprus and its place in the East-Mediterranean framework".
Geologie en Mijnbouw. Vol. 56 (1) pp. 66-82.

DAVIS A.G. (1967)
"The minerology and phase equilibrium of Keuper Marl".
Q.J.E.G., 1, No.1, pp. 25-38.

DEMARS K.R. & CHANEY R.C (1982)
Geotechnical Properties Behaviour and Performance of Calcareous Soils".
ASTM Spec. Publ. No. 777.

DUCLOZ C.E. (1964)
"Revision of the Pliocene and Quaternary Stratigraphy of the Central Mesaoria".
Geol. Mem. Geol. Surv., Cyprus, No. 8

EROL O.A. & DHOWIAN A.W. (1982)
"Swell and shrinkage behaviour of Medinah Active Clays".
J. Eng. Sci. King Saud Univ. Vol 8 (2) pp. 79-84

EVERARD C.E. (1963)
"Contrasts in the form and evolution of hill-side slopes in Central Cyprus".
Inst. Brit. Geogr. Trans., 32, pp. 31-47

FARRAR D.M. & COLEMAN J.D.
"The correlation of Surface Area with other properties of nineteen British clay soils".
J. Soil. Sci. 18, 1967.

FEDA J. (1978)
"Stress in subsoil and methods of final settlement calculation".
Developments in Geotechnical Engineering, Vol 18.
Elsevier Publ.

FOLK R.L. (1974)
"Petrology of Sedimentary rocks".
Hemphill Publ. Co., Texas, 182p

FOOKES P.G. & HIGGINBOTTOM I.E. (1975)
"The classification and description of near-shore carbonate sediments for engineering purposes".
Geotechnique, vol. 25, No. 2 pp 406-411

GASS I.G. (1960)
"The Geology and Mineral Resources of the Dhali area".
Geol. mem. Geol. Surv., Cyprus, No. 4

GAUDRY A. (1862)
"Geologie de l'Ile de Chypre"
Mem. Soc. Geol. France, Ser.2. VII.

GEORGIOU E. & MORGAN D.J. (1979)
"Investigation of Cyprus clay deposits as raw material for structural ceramics - Part 1: geology and mineralogical composition".
Mineralogy Unit, B.G.S. Rep. No. 239

GIBBS H.W. & HOLTZ W.G. (1957)
"Research on determining the density of sands by spoon penetration testing".
Proc. 4th Int. conf. S.M.F.E., London, 1957 Vol.1 pp. 35 - 39

GREY G.R., DARLEY H.C.H., ROGERS W.F. (1980)
"Composition and properties of oil-well drilling fluids".
Gulf. Publ. Co.

HARDY R.M. (1965)
"Identification and performance of swelling soil types".
Canadian Geotechnical Journal, Vol. 11, No. 2, 1965

HENSON F.R.S., BROWNE R.V. & McGINTY J. (1949)
"A Synopsis of the Stratigraphy and Geological history of Cyprus".
Q.J. Geol. Soc. London. 106, pp. 1 - 41.

HOBBS P. & LOUCAIDES G. (1982)
"The Geotechnical map of Nicosia".
G.S.D./B.G.S. Report, April 1982

HOBBS P., HORSEMAN S.T., McEWEN T.J. & YEOW H.Y. (1982)
"Swelling behaviour of Harwell mudrocks"
B.G.S. Report No. E.N.P.U. 82/11

HOLTZ W.G. & GIBBS H.J. (1956)
"Engineering properties of expansive clays"
Trans. A.S.C.E., Vol 121, p. 516

HORSEMAN S.T, HOBBS P., McEWEN T.J., AVERY L., FORSTER A. (1982)
"Basic Geotechnical properties of core from the Harwell boreholes"
B.G.S. Report No. E.N.P.U. 82/7, July 1982

HOUGH B.K. (1957)
"Basic soil engineering"
Ronald Press Co., New York, (2nd ed. 1969)

KATZIR M & DAVID D. (1969)
"Foundations in expansive marl"
2nd Int. Conf. on Expansive Soils Texas A & M Univ. Press 1969

KOMORNIK A. & DAVID D. (1969)
"Prediction of swelling pressure of clays"
journal of the Soil Mech. & Foundtns. Div A.S.C.E, Jan. 1969

KOMORNIK A., LIVNEH M. & SMUCHA S. (1980)
"Shear strength and swelling of clays under suction"
Proc. 4th Int. Conf. on Expansive soils Vol 2, pp. 206 - 226, publ. A.S.C.E. 1980

KOMORNIK A., ROHRLICH V. & WISEMAN G. (1969)
"Overconsolidation by desiccation of coastal late-Quaternary clays in Israel"
Sedimentology, 14, 1970 pp. 125 - 140

LADD C.C. (1964)
"Stress-strain modulus of clay from undrained Triaxial Tests"
Proc. A.S.C.E, Vol 90 No. SM5, Sept, 1964

LAMBE T.W. (1960)
"The character and identification of expansive soils"
Washington D.C. Federal Housing Admin. Tech. Publ. 701

LAMBE & WHITMAN (1979)
"Soil Mechanics"
Published Wiley International

LEONARDS G.A. (ed.) (1962)
"Foundation Engineering"
Publ. McGraw-Hill, Intern. Student edition

LUPINI J.F., SKINNER A.E., VAUGHAN P.R. (1981)
"The drained residual strength of cohesive soils"
Geotechnique, 31, No. 2, p. 181 - 213

MARSLAND A. (1973)
"Large in-situ tests to measure the properties of stiff fissured clays"
B.R.E. report CP 1/73

MATHEWSON C.C. & DOBSON B.M. (1982)
"The influence of geology on the expansive potential of soil profiles"
Geol. Soc. of Amer. Bull., V93, pp 565 - 571 July 1982

MESRI G., ULLRICH G.R. & CHOI Y.K. (1978)
"The rate of swelling of overconsolidated clays subjected to unloading"
Geotechnique 28, No.3, pp. 281 - 307, 1978

MOLNIA B.F. (1974)
"A rapid and accurate method for the analysis of calcium carbonate in small samples"
Journ. Sedim. Petrology. Vol. 44, No.2, pp. 598 - 590

NISHIDA Y. (1956)
"A brief note on compression Index of soil"
Journ of Soil Mech & Foundtn. Eng. Div. A.S.C.E.
Vol 82, No. SM3, Proc. Paper 1027, July 1956
pp. 1027 - 1 to 1027 - 14

PECK HANSON & THORBURN (1974)
"Foundation Engineering"
publ. John Wiley & Sons, New York, 2nd Ed.

PENMAN A.D.M. & GODWIN E.W. (1975)
"Settlement of buildings and Associated Damage"
B.R.E. Current Paper 33/75

PERLOFF W.H. & BARON W. (1976)
"Soil Mechanics Principles and Applications"
Publ. Ronald, New York.

POULOS H.G. & DAVID E.H. (1974)

"Elastic Solutions for soil and Rock Mechanics"
Publ J. Wiley & Sons, New York

PUSCH R. (1980)

"Swelling pressure of highly compacted bentonite"
SKBE/KBS Teknisk Rapport 80 - 13, 1980

REED F.R.C. (1930)

"Contributions to the Geology of Cyprus (Part II): The Tertiary Formations"
Geol. Mag. LVX II

REED F.R.C. (1935)

"Notes on the Neogene faunas of Cyprus, III: The Pliocene Faunas"
Ann. Mag. Nat. Hist. Ser. 10 Vol XVI

RENDEN HERRERO O. (1980)

"Universal compression index equation"
Journ. Geotech Eng. Div A.S.C.E. No. GT 11 Nov. 1980
pp. 1179 - 1200

ROBERTSON A.H.F. (1977)

"Tertiary uplift history of the Troodos Massif, Cyprus"
Geol. Soc. of Amer Bull v88 1763 - 1772

RUSSELL R. (1882)

"On the Geology of the Island of Cyprus"
Q.J. Geol. Soc. London, 105, pp. 1 - 41

SARNTHEIN M & WALGER E. (1973)

"Classification of modern marl sediments in the Persian Gulf by factor analysis"
The Persian Gulf, pp. 81 - 98, Springer Verlag, Berlin

SAUNDERS M.K. & FOOKES P.G. (1970)

"A review of the relationship of Rock Weathering and climate and its significance to Foundation Engineering"

SCHMERTMANN J.H. (1969)
"Swell Sensitivity"
Technical Note, Geotechnique, 19, pp. 530 - 533

SCHMERTMANN J.H. (1953)
"Estimating the true consolidation behaviour of clay from laboratory test results"
Proc. A.S.C.E. 79, seperate 311, 26 pp.

SCHMIDT S. 81963)
"Untersuchungen uber das Pliozan der Insel Cypern I-Ein wurmrohren (Serpuliden) - Bryozoenriff - Horizont, Sudlich, Leucossia (Nicosia, Cyprus)"
Ann. Geol. Pays Helleniques 14

SEED H.B., WOODWARD R.J. & LUNDGREN R. (1962)
"Prediction of swelling potential for compacted clays"
A.S.C.E. J. soil. mech., 88, No. SM3, pp. 53 - 87

SKEMPTON A.W. (1961)
"Horizontal stresses in an overconsolidated Eocene clay"
Proc. 5th, Int. Conf. soil. mech. Paris, 1, pp. 351 - 58

SKEMPTON A.W. (1964)
"Long term stability of clay slopes"
Geotechnique, 14, pp. 77 - 101

SPANGLER M.G. & HANDY R.L. (1982)
"Soil Engineering"
4th Ed. Publ. Harper & Row, New York

SRIDHARAN A. & ALLAM M.M. (1982)
"Volume change behaviour of desiccated soils"
A.S.C.E. J. Soil Mech. GT8 Aug. 1982

STAMATOPOULOS A.C. & KOTZIAS P.C. (1978)
"Soil compressibility as measured in the oedometer"
Geotechnique, Vol. 28, pp 363 - 375

TERZAGHI K. & PECK R.B. (1967)
"Soil Mechanics in engineering practice"
2nd Ed. J. Wiley & Sons. Wiley Intern. Ed. New York

WARKENTIN B.P. & BOZOZUK M. (1961)
"Shrinking and swelling properties of two Canadian clays"
Proc. I.C.S.M.F.E., 5th Paris, 3A, p.851

WILLIAMS & JENNINGS (1977)
"The in-situ behaviour of fissured soils"
Proc. I.C.S.M.F.E., 9th, Vol. 2, Tokyo

YONG R.N. & WARKENTIN B.P. (1975)
"Soil properties and behaviour"
Elsevier Publ. Amsterdam.

B.S. 1377 (1975)
"Methods of testing for soils for engineering purposes"
British Standards Institute publ., April 1975

BUILDING RESEARCH ADVISORY BOARD (1968)
"Criteria for selection and design of residential slabs-on-ground"
Federal Housing Admin. Report No. 33

C.P. 2004 (1972)
"Code of practice for foundations"
British Standards Institute publ. Sept. 1972

Report of the sub-committee on Standardisation of penetration Testing in Europe.

Proc. 9th I.C.S.M.F.E., Vol. 3, 1977, Tokyo (App.5)

PHOTOGRAPHIC LOG OF

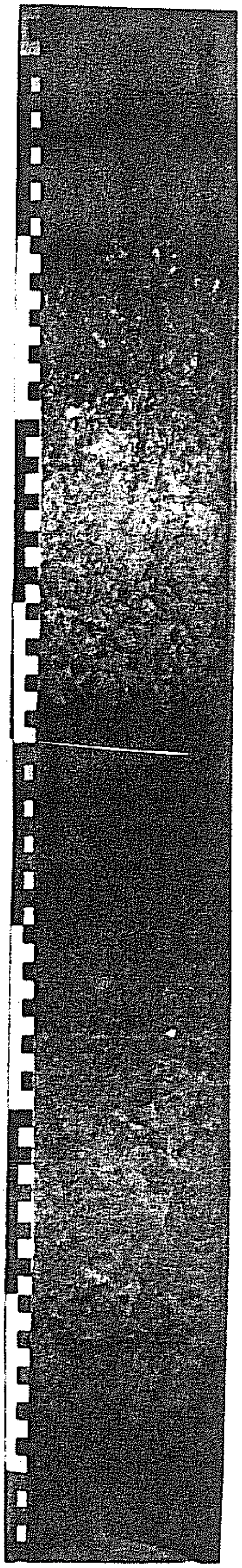
B.H. EG 20/83

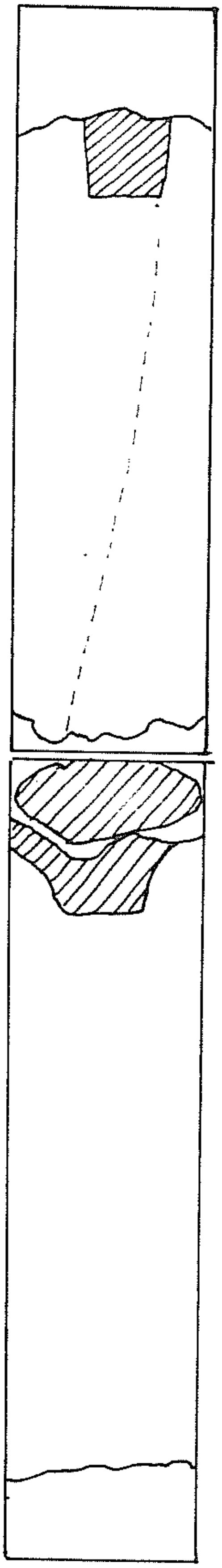
KEY:

⬯	PRIMARY VEINING (GREY COLOURED)
⬬	SECONDARY VEINING (USUALLY DARKER GREY)
◌	CONCENTRATION OF IRON OXIDE
••••	MANGANESE OXIDE (STAINING USUALLY IN JOINT OR FISSURE)
— —	FISSURE, JOINT OR SEPARATED BEDDING PLANE
〰	BANDING (DUE TO DIFFUSION)
🐚	SHELL, FOSSIL
▨	MATERIAL DISTURBED BY DRILLING OPERATIONS

N.B. Colour codes referred to are taken from the Munsell Soil Colour Chart (see Ref. list) e.g. 2.5Y5/6 indicates a yellowish 'hue' (2.5Y), a 'value' (darkness) of 5 on a scale of 1 → 10, and a 'chroma' (strength) of 6 on a scale of 1 → 8.

2.5Y5/4	light olive brown
2.5Y5/6	" " "
2.5Y6/4	light yellowish brown
5Y6/2	light olive grey
5Y5/1	grey
10YR6/8	brownish yellow



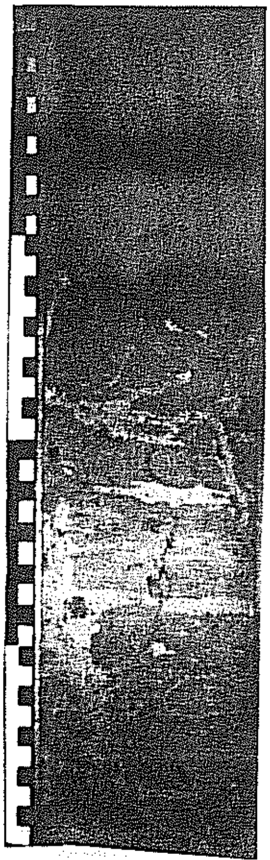


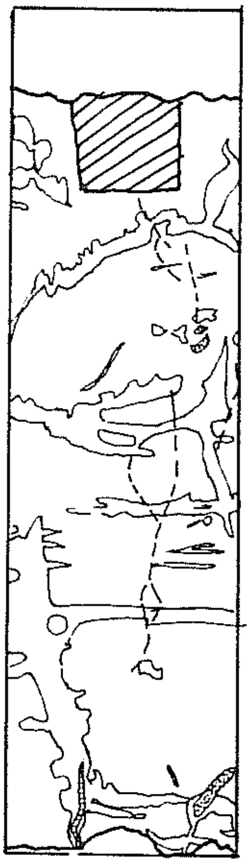
Depth: 1.0 - 1.5 m

Dry, friable, highly fiss$^{\underline{d}}$., 2.5 Y 6/4 clayey silt (reworked MARL) with some med. gravel and sand (igneous). A few pockets of carbonate. Some slickensiding on 45^{o} fissures. Traces of manganese staining on fissures. Hcl reaction.

Depth: 1.5 - 2.0 m

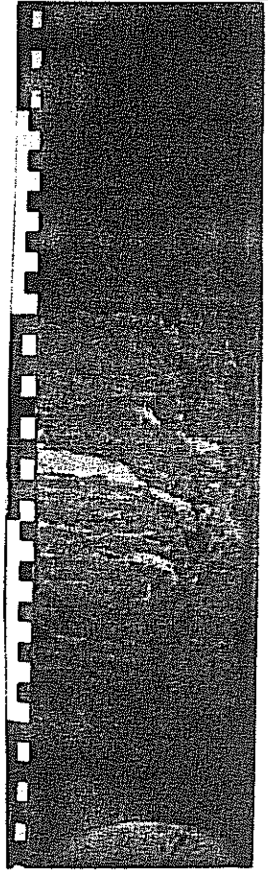
Alternating bands of slightly fossiliferous mottled 2.5 Y 6/4 and 5 Y 6/2 f. sandy silt (sandy MARL); probably reworked. Sandy marl is friable, open and structureless whereas marl is highly fissured. Small borings or rootlets throughout some pockets of carbonate and little f-m gravel (igneous). Hcl reaction.

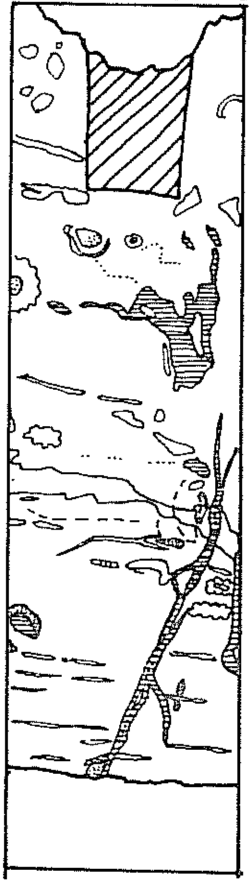




Depth: 2.0 - 2.5 m

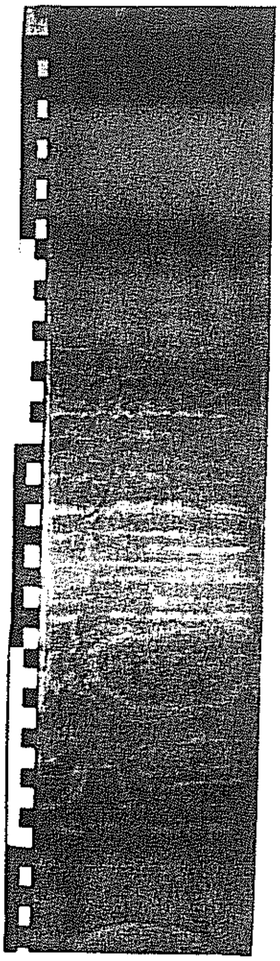
Hard, fissured, 2.5 Y 5/6 clayey silt (MARL) with pronounced veining of softer 5 Y 6/2 clayey silt and silty clay (MARL) associated with sub-vertical and also sub-horizontal fissuring with some slickensiding. Horiz. veins tend to be slightly sandier. Laminations of f. sandy silt in both materials. Strong dendritic manganese staining in fissures. Hcl reaction throughout. A 'secondary' darker coloured veining visible at base.

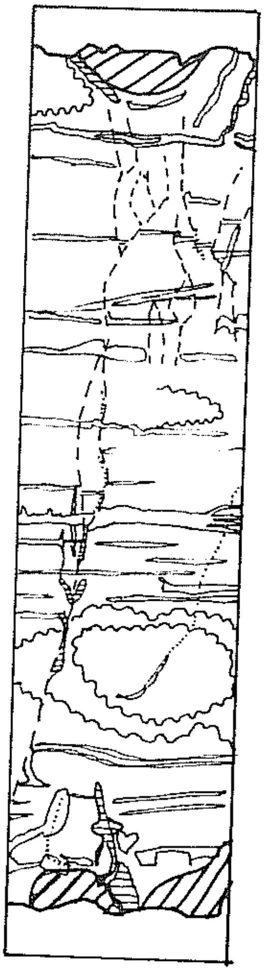




Depth: 2.5 - 3.0 m

As above; main vein is noticeably plastic soft clay. At centre of horiz. veins is a very thin lamination of very fine sand or coarse silt associated with heavy manganese staining. Heavy fissuring and slickensiding predominates near main sub-vert. vein. 'Secondary' darker veining cuts through primary vein. Hcl reaction throughout.

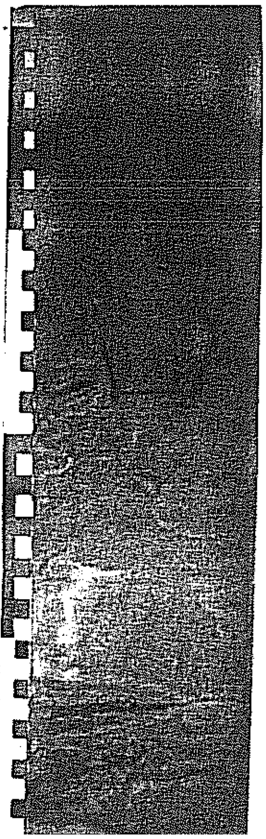


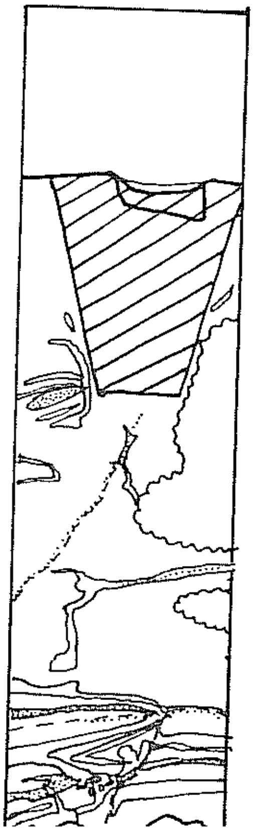


Depth: 3.5 - 4.0 m

Horizontally laminated hard, fissured silty clay and clayey silt (MARL) 2.5 Y 5/6 with laminations and veins of 5 Y 6/2. Sub. vert. fissures have slickensiding and manganese staining; shear displacements of a few mm's. Some coinchoidal fracturing in 2.5 Y 5/6 marl and circular banding (i.e. discoloration) probably due to percolation through marl mass. Horiz. laminations are coarser than bulk. Hcl reaction throughout.

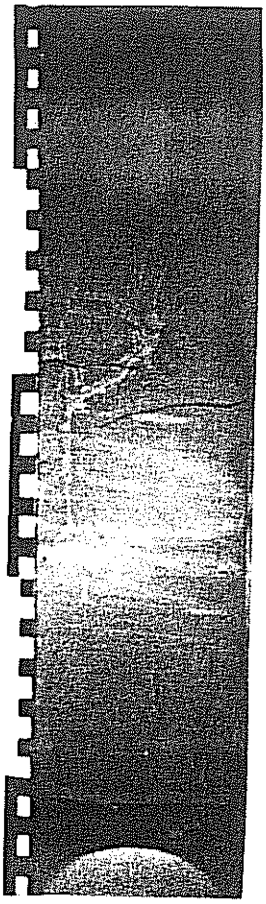
Note: drilling disturbance is negligible.

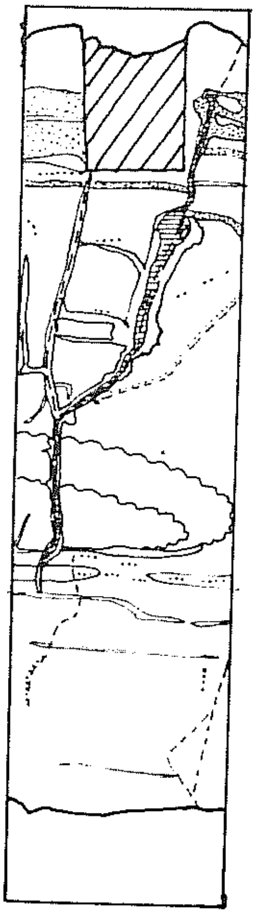




Depth: 4.5 - 5.0 m

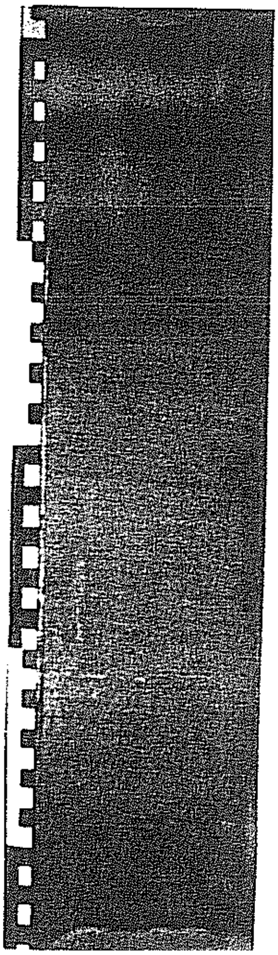
MARL as above, but few horiz. laminations and more prominent circular banding. Fissuring and veining is much reduced. Fissures are closed and coated with a very thin smear of light coloured clay, manganese staining, and at the base iron oxide. Fine laminations contain thin sandier material. Slickensiding on sub. vert. fissures. Hcl reaction.

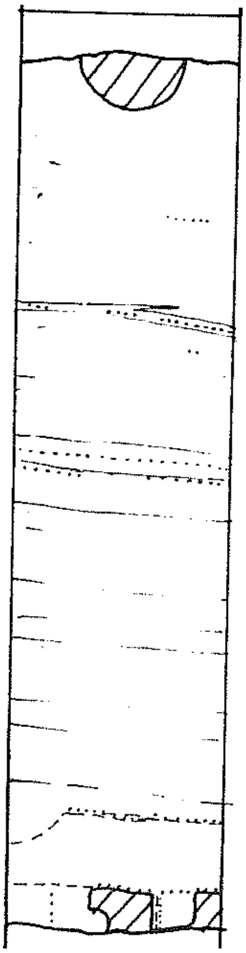




Depth: 5.5 - 6.0 m

Firm-hard laminated silty clay and clayey silt (MARL) 2.5 Y 5/4 with veins of 5 Y 6/2 (primary) and 5 Y 5/1 (secondary). Major sub. vert. vein cuts horiz. laminations and circular banding (centre). Small shear displacement on fissures. Manganese staining on most fissures. Veins interconnected horizontally. Hcl reaction throughout.

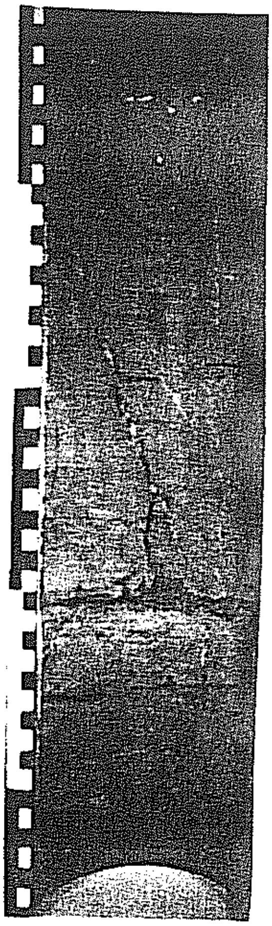


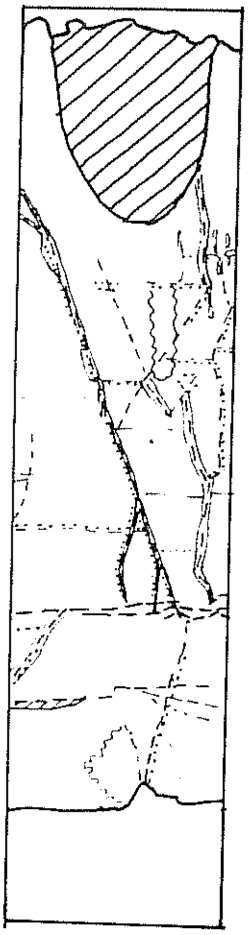


Depth: 6.5 - 7.0 m

Hard, laminated, uniform. No fissures except at base. No veining except for horiz. laminations. Manganese staining on some open laminations. Material generally finer and more competent than above. Little drilling disturbance. Hcl reaction throughout.

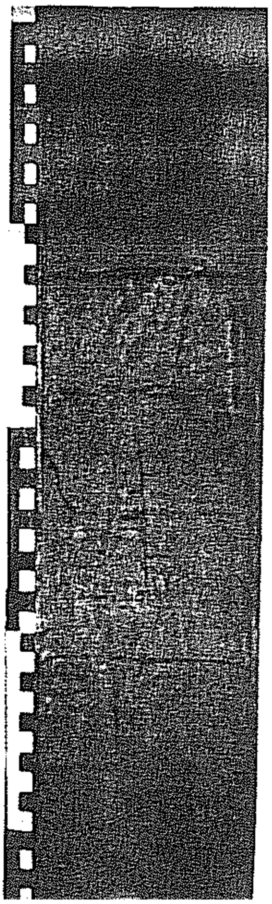
Note: vert. fissure at base terminated by horiz. lamination.

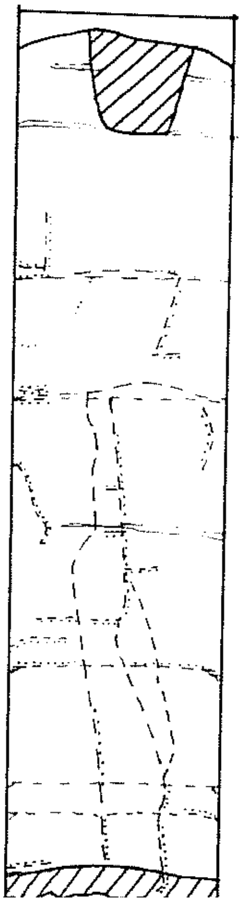




Depth: 7.5 - 8.0 m

Strongly fissured, hard, laminated 2.5 Y 5/6 silty clay and clayey silt (MARL). Interconnected sub. vert. veins contain soft 5 Y 6/2 clay and manganese staining. Shear displacements vary from 2 to 10 mm. Some closed fissures contain no 5 Y 6/2 clay only manganese staining. Some disturbance at open horiz. fissures (lower half) where coarser material has possibly been lost. Slickensiding is seen in both 2.5 Y 5/6 and 5 Y 6/2 material. Hcl reaction throughout.

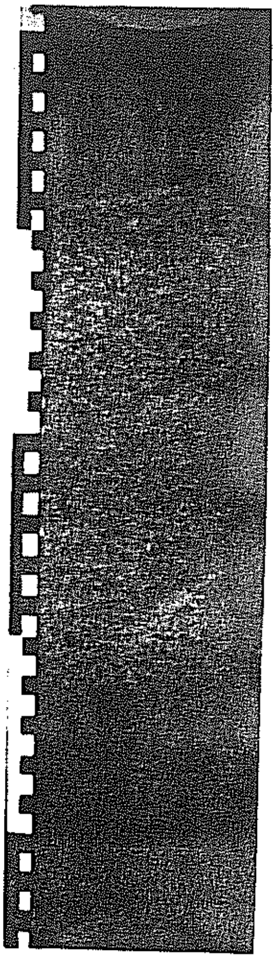


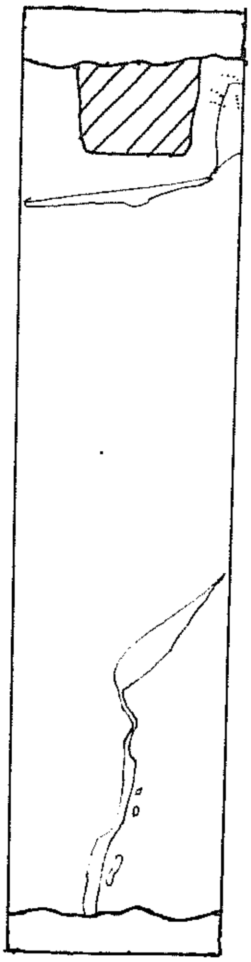


Depth: 8.5 - 9.0 m

Fissured, laminated, firm, 2.5 Y 5/6 silty clay (MARL). Little veining but sub. vert. manganese coated fissures and separation along some horiz. planes. Small displacements on fissures. Hcl reaction.

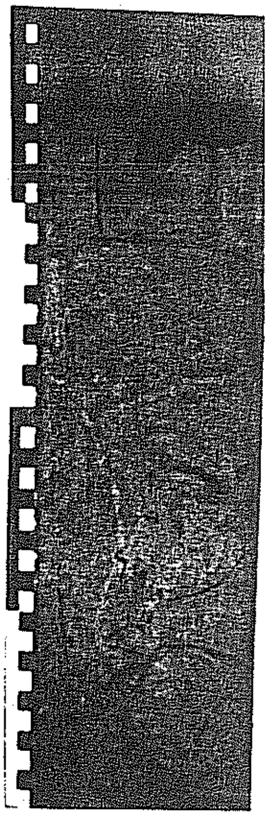
Note: slight downwarping in lower half due to drilling disturbance.

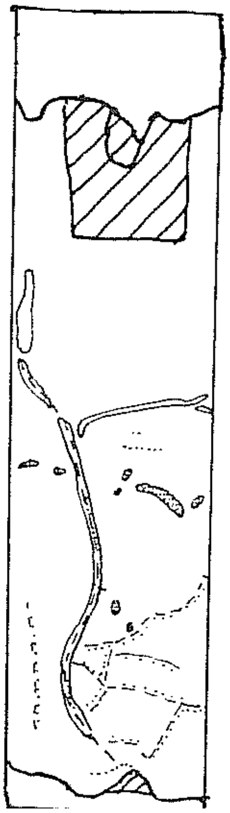




Depth: 9.5 - 10.0 m

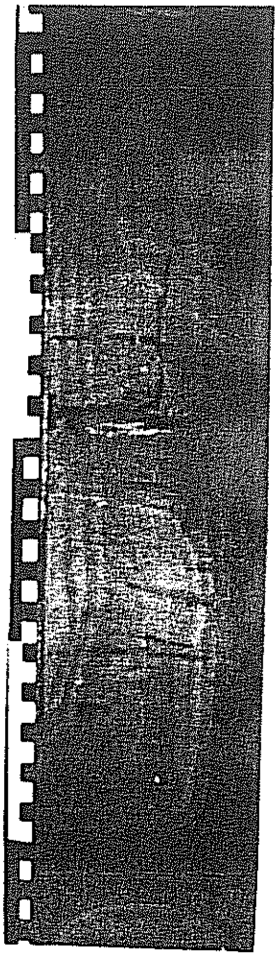
Soft-firm friable 10 YR 6/8 silty f. sand (SAND). Lower half has vein of 5 Y 6/2 clay. Upper 50 mm is soft (probably disturbed) 2.5 Y 5/6 silty CLAY with manganese staining. The SAND stratum is water bearing. Hcl reaction throughout.

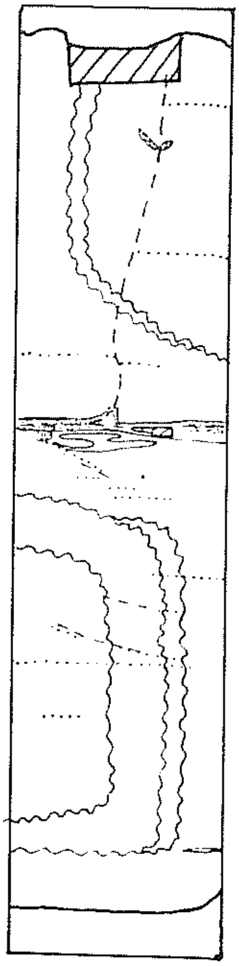




Depth: 10.5 - 11.0 m

Stiff-hard, fissured, mottled (2.5 Y 5/6 - 5 Y 6/2) slightly (f.) sandy, clayey silt (MARL). Sub. vert. veining of 5 Y 6/2 clay with manganese staining. Patches of iron oxide concentration. Some softening in top 10 cm due to drilling disturbance. Hcl reaction throughout.

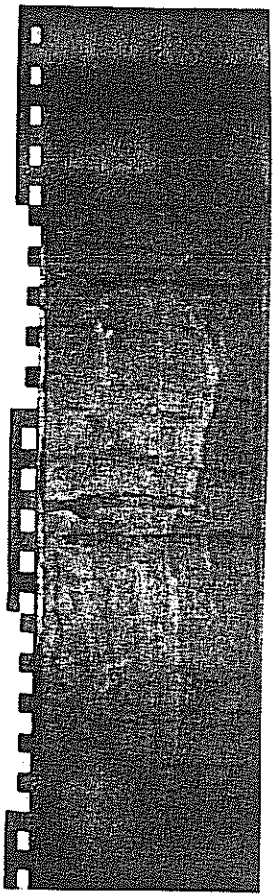


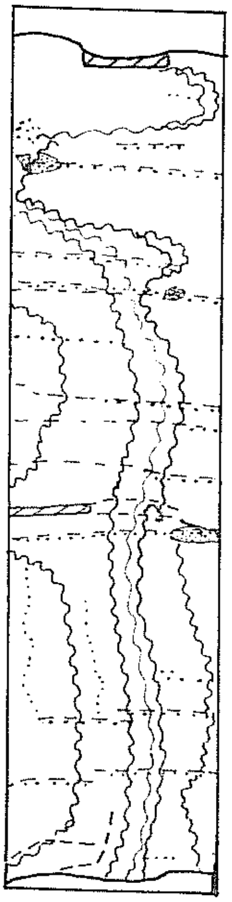


Depth: 11.5 - 12.0 m

Hard, slightly fissured, 2.5 Y 5/6 clayey silt (MARL). Few horiz. laminations contain manganese as well as carbonate and iron oxide deposits. Large scale circular banding either side of central open horiz. fissure. Sub. vert. fissure with 2-3 mm shear displacement extends upward and cuts both horiz. fissures and circular banding. Hcl reaction.

Note: opposite direction of percolation (?) in top and bottom halves.



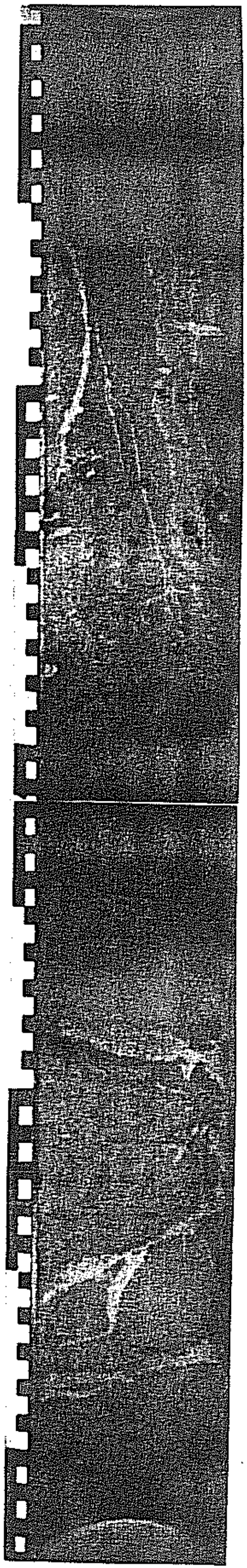


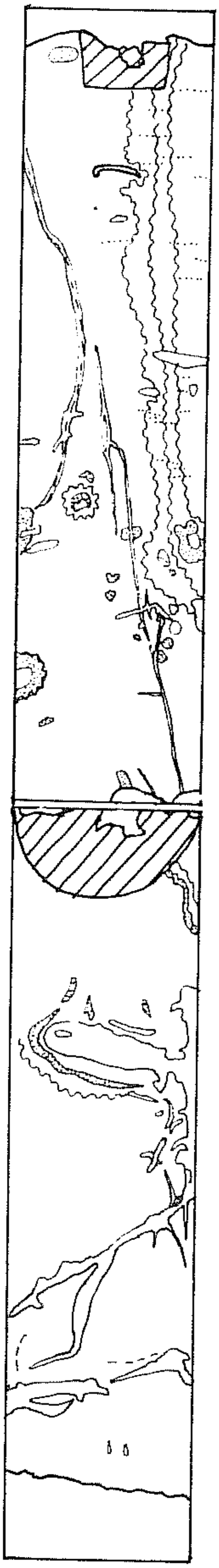
Depth: 12.5 - 13.0 m

As above (MARL) but few small sub vert. fissures. Horizontal fissuring more marked.

Note: circular banding pattern is cut and slightly displaced by horiz. fissures. Also note left to right direction of percolation (?).

Hcl reaction.





Depth: 14.5 - 15.0 m

Firm, slightly veined, 2.5 Y 5/6, clayey silt/silty clay (MARL) with sub. vert. veins of 5 Y 6/2 clay. Mainly vert. banding due to percolation (right to left?). Very thin laminations containing manganese in upper half of core. Patches of iron oxide concentrations in lower half of core. Small shear displacement along vert. vein.

Note: horiz. oriented fossil shell (top centre) detoured by banding.

Hcl reaction.

Depth: 15.0 - 15.5 m

As above (MARL) with more marked vert. and sub. horiz. veining of 5 Y 6/2 clay. Particularly large body of 5 Y 6/2 clay above centre of core with hard iron oxide-rich band around it. Upper 10 cm of core is soft probably due to drilling disturbance. Little manganese staining. Hcl reaction.

APPENDIX 1

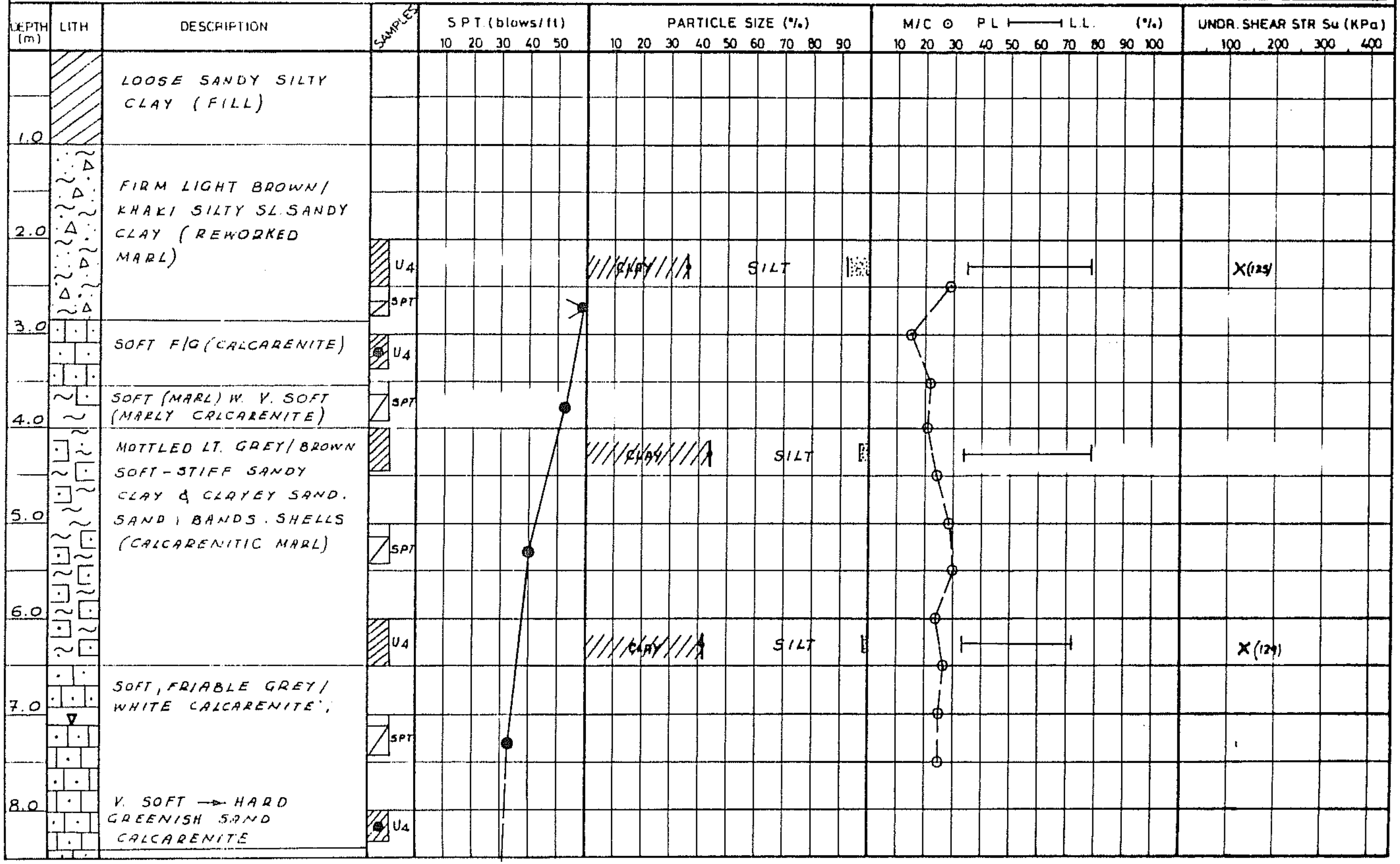
BH No E G 7/82

SITE: M A K E D H O N I T I S S A

GRID REF: 5 28425 E, 38 89130 N G/L 187m. W/T 7.2 m

DATE: 12/5/82

PAGE: 1



DEPTH (m)	DESCRIPTION
0 – 1.0	LOOSE SANDY SILTY CLAY (FILL)
1.0 – 2.9	FIRM LIGHT BROWN/ KHAKI SILTY SL. SANDY CLAY (REWORKED MARL)
2.9 – 3.6	SOFT F/G (CALCARENITE)
3.6 – 4.1	SOFT (MARL) W. V. SOFT (MARLY CALCARENITE)
4.1 – 6.5	MOTTLED LT. GREY/BROWN SOFT-STIFF SANDY CLAY & CLAYEY SAND. SAND I BANDS. SHELLS (CALCARENITIC MARL)
6.5 – 7.9	SOFT, FRIABLE GREY/ WHITE CALCARENITE',
7.9 –	V. SOFT → HARD GREENISH SAND CALCARENITE

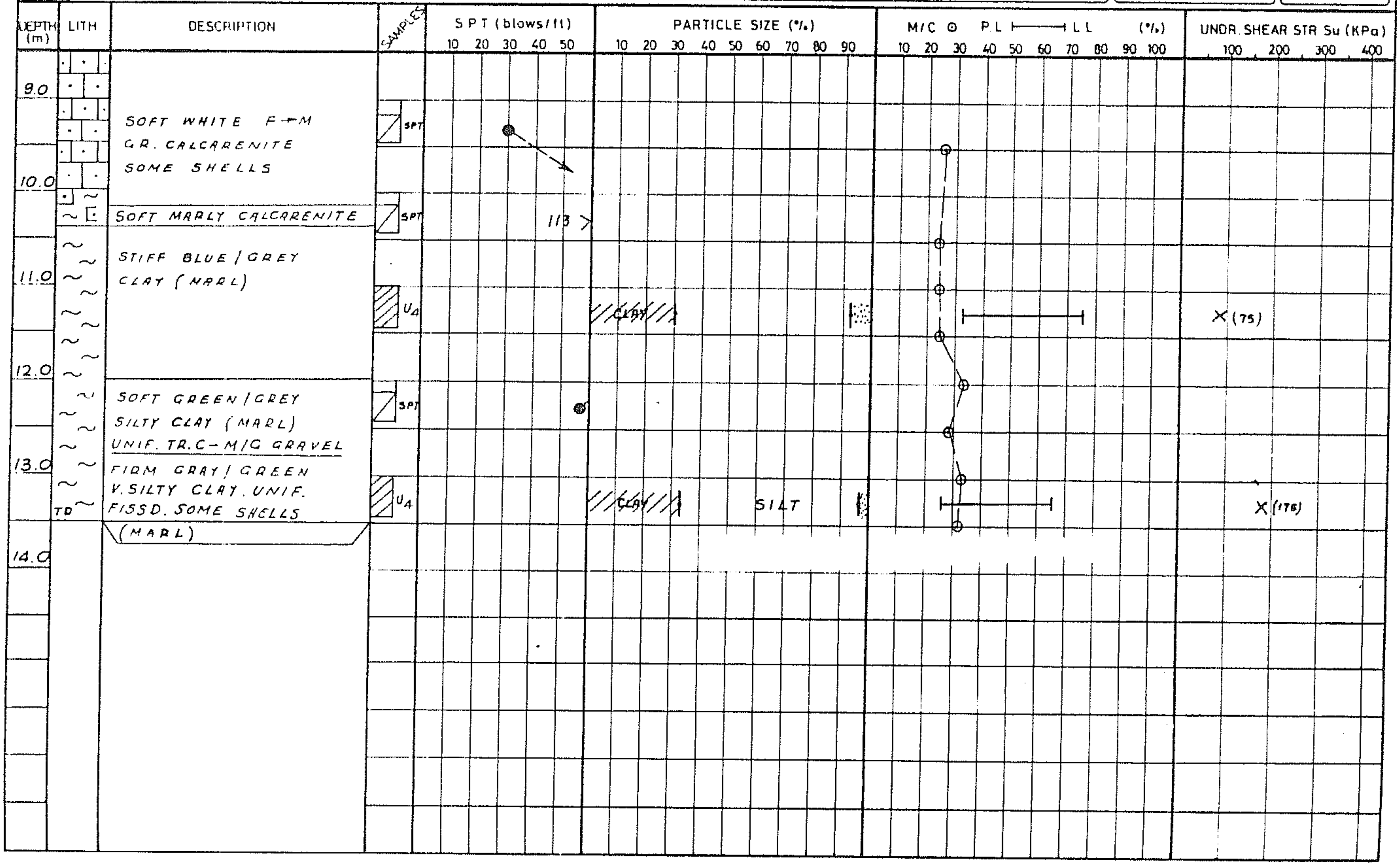
BH No. EG 7/82

SITE: MAKEDHONITISSA

GRID REF: 5 284 25 E, 38 891 30 N G/L 187 m W/T 6.2 → 6.4 m

DATE: 12/5/82

PAGE: 2



SOFT WHITE F→M
GR. CALCARENITE
SOME SHELLS

SOFT MARLY CALCARENITE

STIFF BLUE / GREY
CLAY (MARL)

SOFT GREEN / GREY
SILTY CLAY (MARL)
UNIF. TR. C–M/C GRAVEL

FIRM GRAY / GREEN
V. SILTY CLAY. UNIF.
FISSD. SOME SHELLS
(MARL)

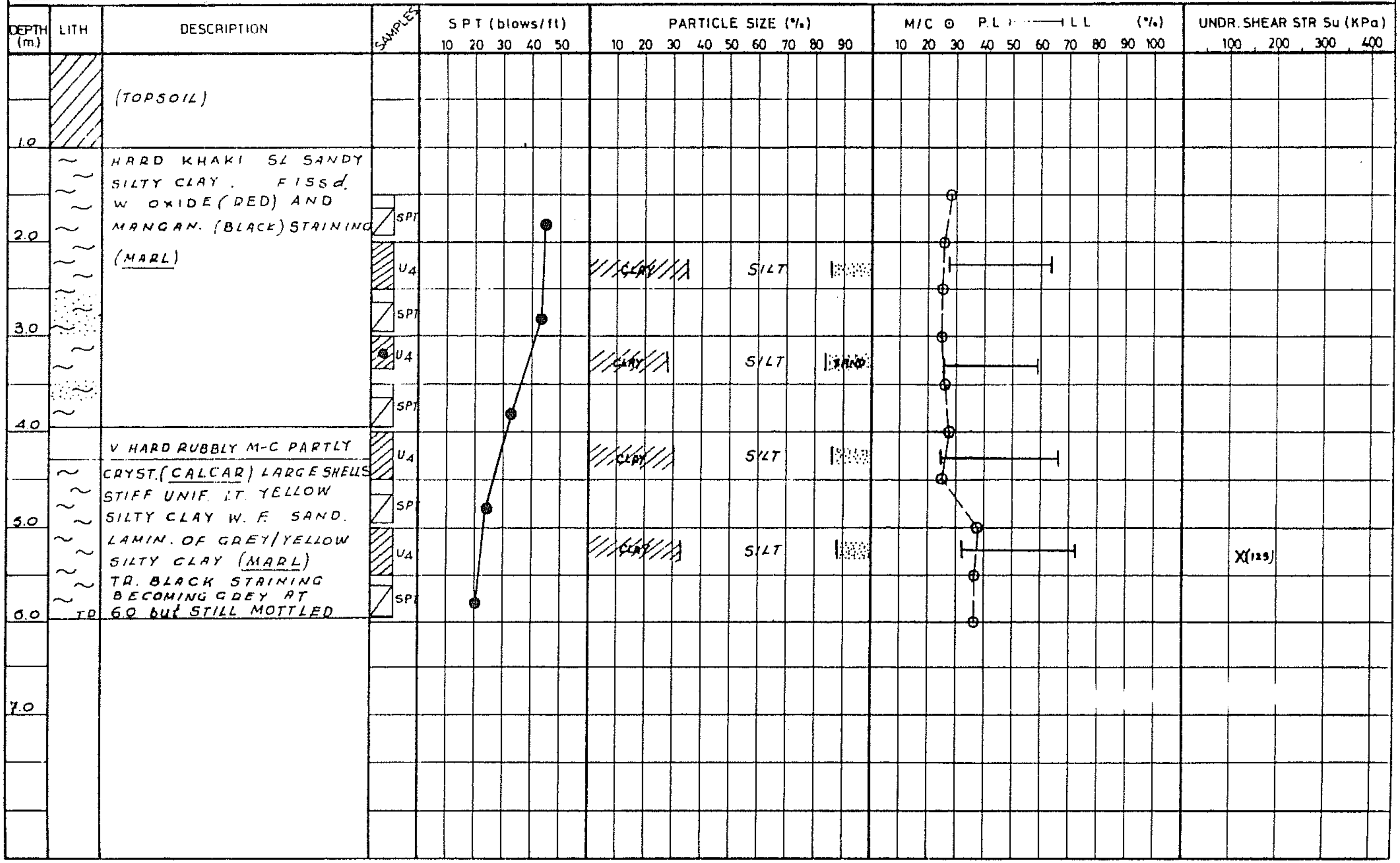
BH. No. EG 8/82 RE-DRILLED CLOSE BY DUE TO BROKEN BIT AT 4.00 m

SITE: NAL EXHIBITION CENTRE

GRID REF: 5 288 80 E, 38 903 40 N G/L 173 m. W/T DRY

DATE: 19/5/82

PAGE: 1



(TOPSOIL)

HARD KHAKI SL SANDY SILTY CLAY. FISSd. W OXIDE (RED) AND MANGAN. (BLACK) STAINING (MARL)

V HARD RUBBLY M-C PARTLY CRYST. (CALCAR) LARGE SHELLS

STIFF UNIF. LT. YELLOW SILTY CLAY W. F. SAND. LAMIN. OF GREY/YELLOW SILTY CLAY (MARL) TR. BLACK STAINING BECOMING GREY AT 6.0 but STILL MOTTLED

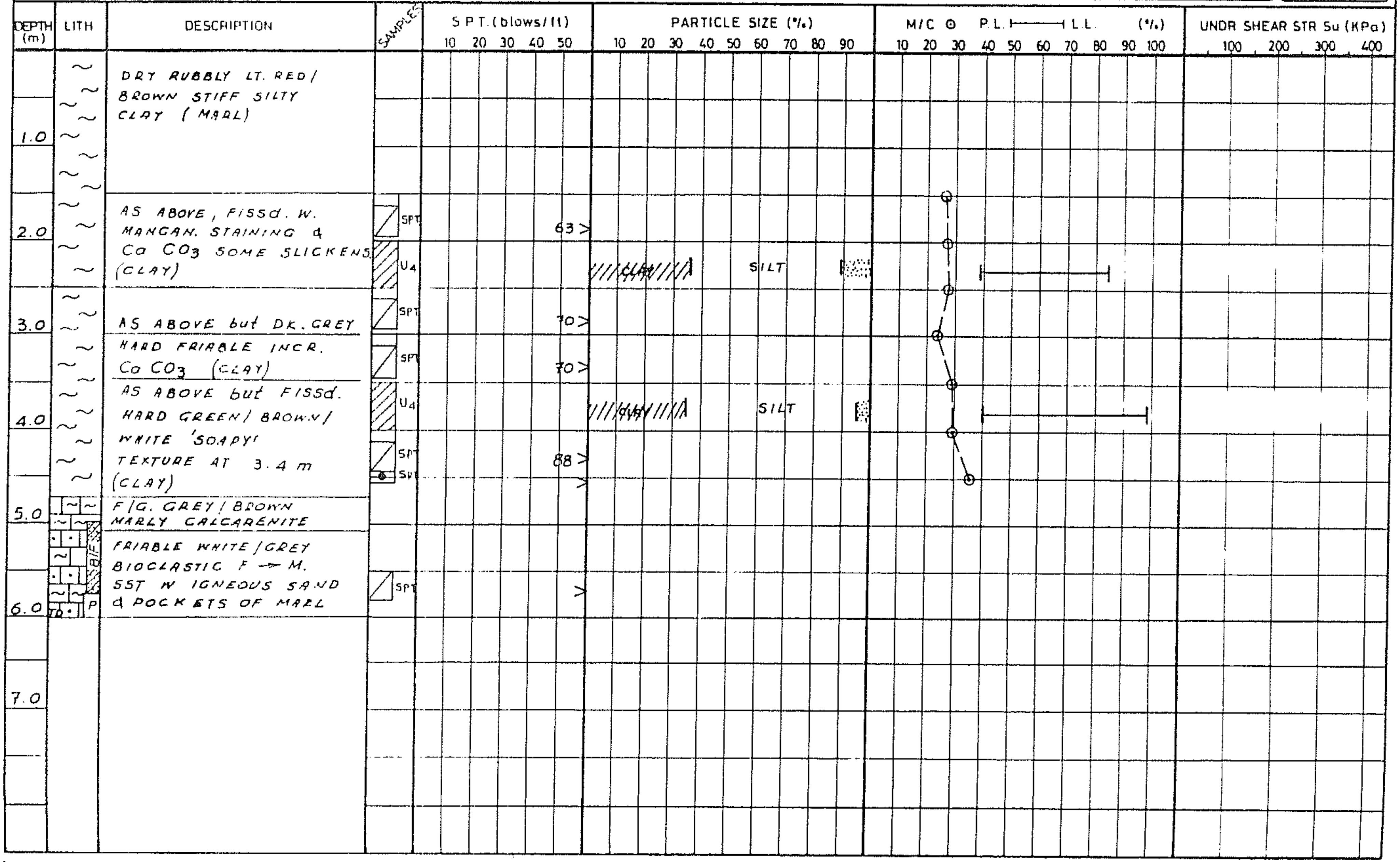
BH. No EG 9/82

SITE: ANTHOUPOLIS

GRID REF: 526993 E, 3886916 N G/L 230 m. W/T DRY

DATE: 20/5/82

PAGE: 1



DRY RUBBLY LT. RED/ BROWN STIFF SILTY CLAY (MARL)

AS ABOVE, FISSd. W. MANGAN. STAINING & $CaCO_3$ SOME SLICKENS (CLAY)

AS ABOVE but DK. GREY

HARD FRIABLE INCR. $CaCO_3$ (CLAY)

AS ABOVE but FISSd. HARD GREEN/ BROWN/ WHITE 'SOAPY' TEXTURE AT 3.4 m (CLAY)

F/G. GREY/ BROWN MARLY CALCARENITE

FRIABLE WHITE/GREY BIOCLASTIC F → M. SST W IGNEOUS SAND & POCKETS OF MARL

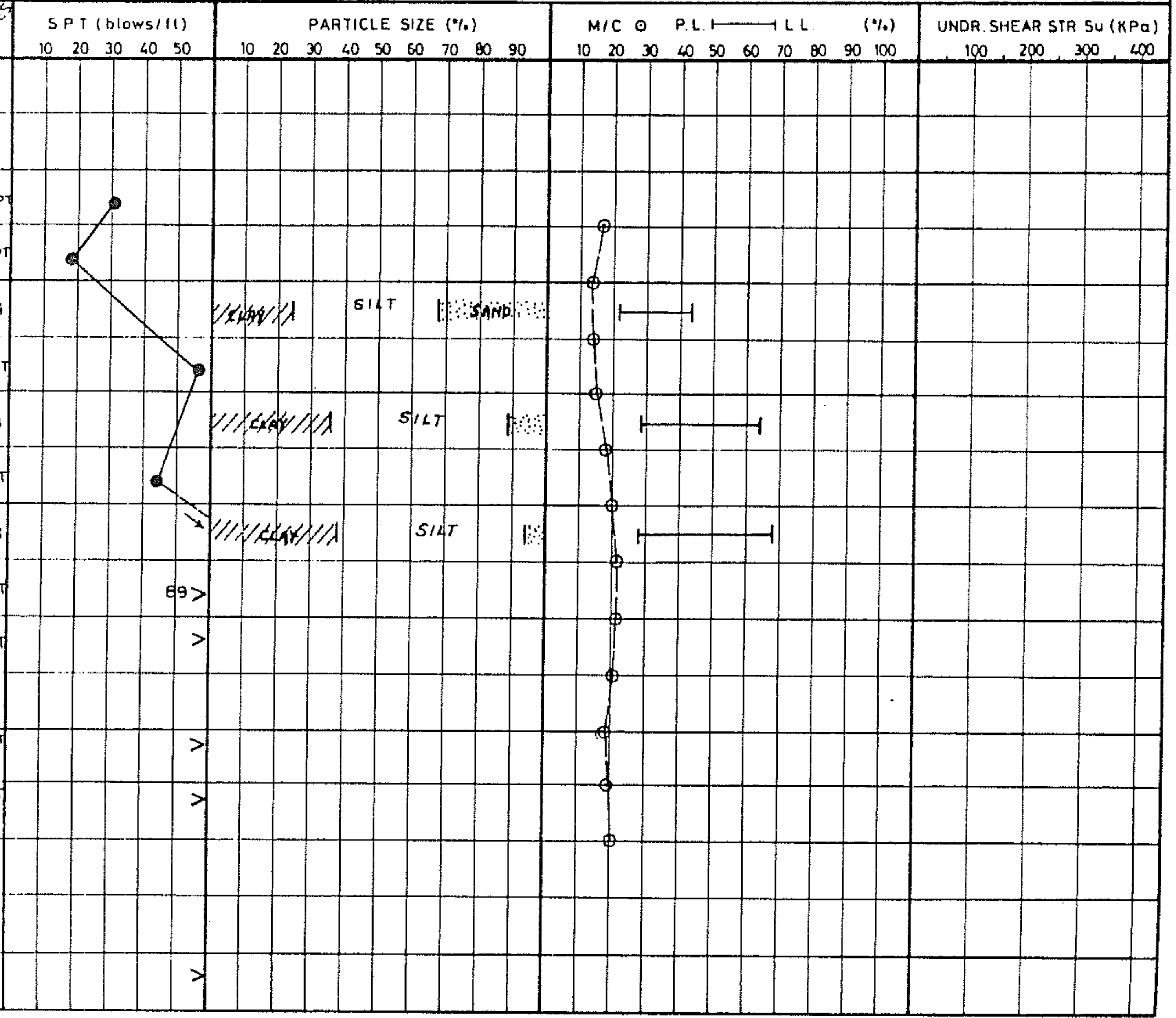
BH No. BH 13/82

SITE: ANTHOUPOLIS
GRID REF: 5 26/18 E, 38 86/15 N G/L 248 m W/T DRY —

DATE: 7/6/82

PAGE: 1

DEPTH (m)	LITH	DESCRIPTION	SAMPLES
1.0		SILT SAND & CLAY W. GRAVEL (TOPSOIL)	
2.0 3.0 4.0		REDDISH BROWN SANDY SILT W. SOME CLAY CALC. COATED F. GRAVELS OF IGNEOUS & SEDIM. ORIGIN (REWORKED SOIL)	SPT SPT U4 SPT U4 SPT
5.0		FISSd. RED/BROWN SILTY CLAY; CALC. CEMENT; MANGAN. STAINING ON FISSURES (APALOS MARL)	U4 SPT SPT
6.0		AS ABOVE BUT WHITE /BROWN COLOUR	SPT SPT
7.0 8.0		F→C. IGNEOUS & SEDIM GRAVEL W. LENSES OF SAND. SOME COBBLES (GRAVELS)	U4 SPT



BH No BH 13/82

SITE: ANTHOUPOLIS
GRID REF: 5 261 18 E, 88 861 15 N G/L 248 m W/T DRY

DATE: 7/6/82

PAGE: 2

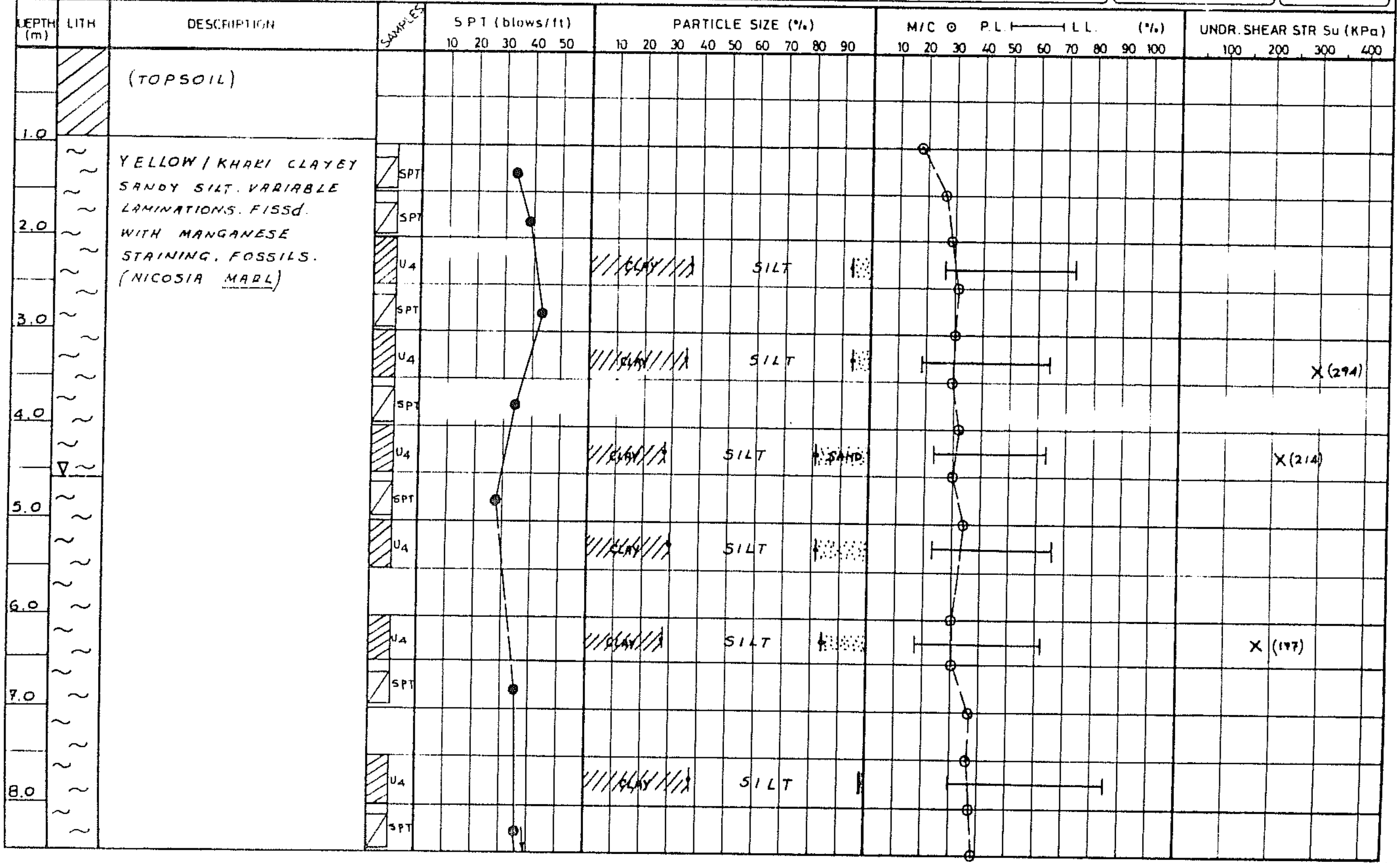
DEPTH (m)	LITH	DESCRIPTION	SAMPLES	S P T (blows/ft) 10 20 30 40 50	PARTICLE SIZE (%) 10 20 30 40 50 60 70 80 90	M/C ⊙ P.L. ├──┤ L.L. (%) 10 20 30 40 50 60 70 80 90 100	UNDR. SHEAR STR Su (KPa) 100 200 300 400
9.0							
			SPT	●			
10.0			SPT	100 >			
	↓	GRAVELS					
11.0							

BH No EG 14/82

SITE: LYKAVITOS SCHOOL
GRID REF: 5 33715 E, 38915 10N G/L 146 m. W/T 3.5 – 4.7

DATE: 10/6/82

PAGE: 1



(TOPSOIL)

YELLOW / KHAKI CLAYEY SANDY SILT. VARIABLE LAMINATIONS. FISSd. WITH MANGANESE STAINING. FOSSILS. (NICOSIA MARL)

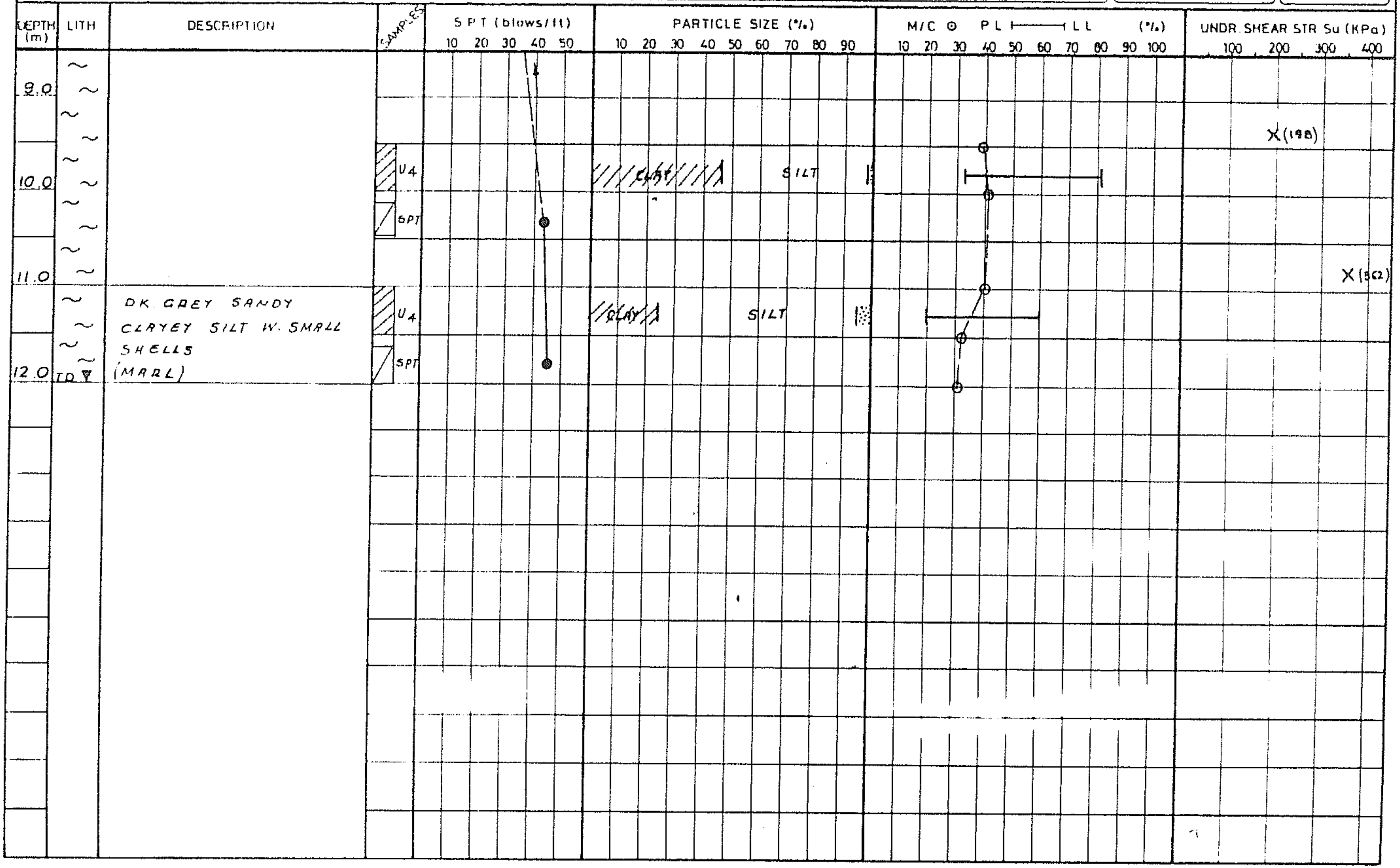
BH No EG 14/82

SITE: LYKAVITOS SCHOOL

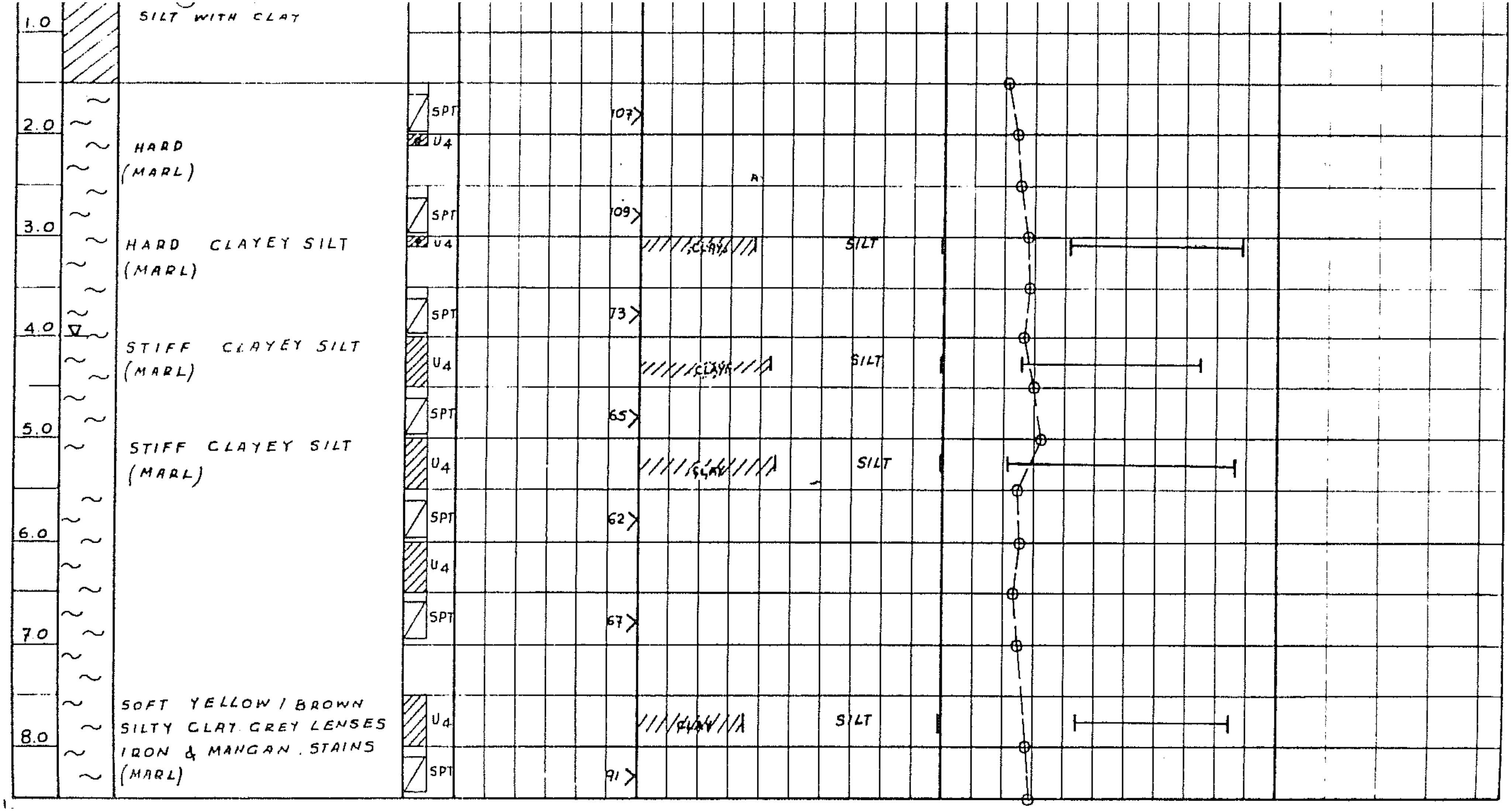
GRID REF: 533715 E, 3891310 N G/L 146 m. W/T 3.5 - 4.7

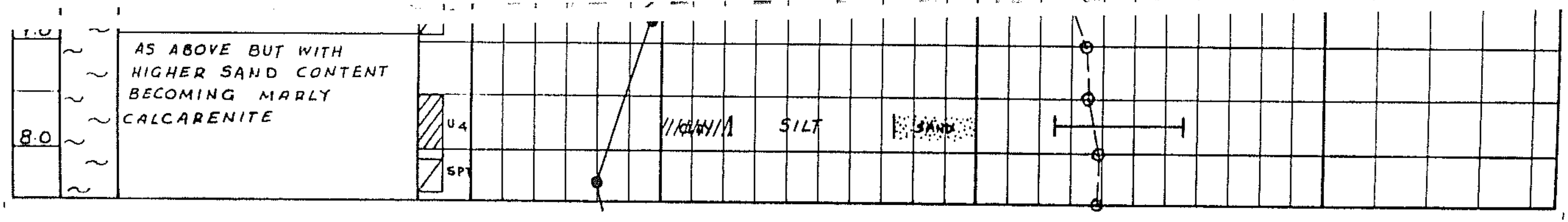
DATE. 10/6/82

PAGE: 2



DK. GREY SANDY CLAYEY SILT W. SMALL SHELLS (MARL)


1.0
SILT WITH CLAY
2.0
HARD
(MARL)
3.0
HARD CLAYEY SILT
(MARL)
4.0
STIFF CLAYEY SILT
(MARL)
5.0
STIFF CLAYEY SILT
(MARL)
6.0
7.0
SOFT YELLOW / BROWN
SILTY CLAY GREY LENSES
IRON & MANGAN. STAINS
(MARL)
8.0
SPT
U4
SPT
U4
SPT
U4
SPT
U4
SPT
U4
SPT
U4
SPT
107
109
73
65
62
67
91
CLAY
SILT
CLAY
SILT
CLAY
SILT
CLAY
SILT


AS ABOVE BUT WITH
HIGHER SAND CONTENT
BECOMING MARLY
CALCARENITE
8.0
U4
SPT
CLAY
SILT
SAND

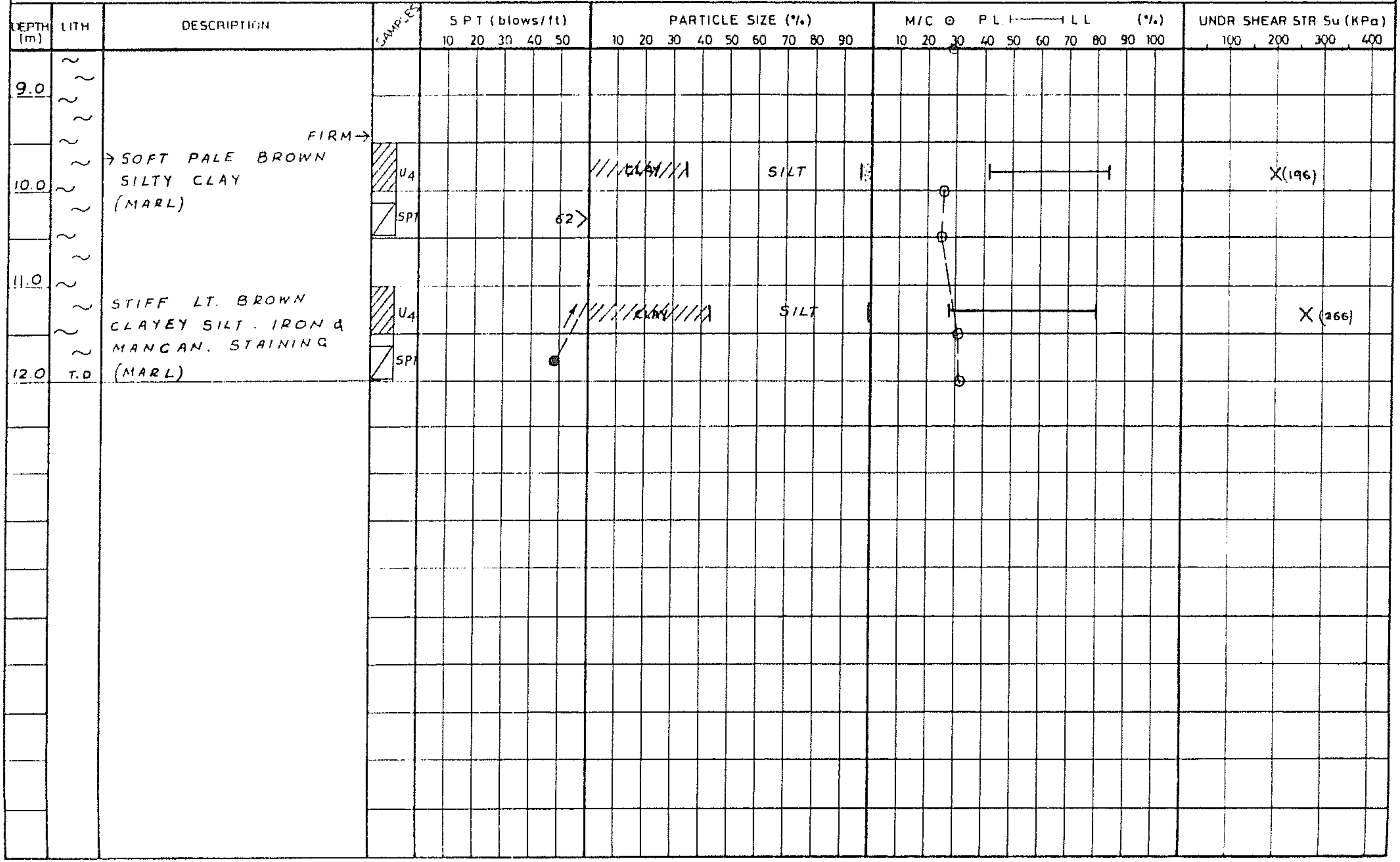
BH No EG 18/82

SITE. AYIA VARVARA

GRID REF. 535794 E, 3892607 N G/L 139 m W/T 3.5 – 4.4 m

DATE: 30/6/82

PAGE: 2



FIRM→

→SOFT PALE BROWN SILTY CLAY (MARL)

STIFF LT. BROWN CLAYEY SILT. IRON & MANGAN. STAINING (MARL)

Borehole EG	Sample Depth	Calcite	Dolomite	Quartz	Feldspar	Ca-montmor	Mica	Chlorite	Gypsum
8/82	2.0 – 2.5 4.0 – 4.5 5.0 – 5.5	** ** ***	Tr. ** *	** * *	* Tr. *	Present " "	Present " "	Present " "	N. M. " "
9/82	3.5 – 4.0	***	N.D.	*	Tr.	"	"	"	"
14/82	2.0 – 2.5 6.0 – 6.5 9.5 – 10.0 11.0 – 11.5	** *** *** **	* ** * **	* ** ** *	* ** * *	" " " "	" " " "	" " " "	" " " "
18/82	3.0 – 3.5 11.0 – 11.5	** **	* **	* **	* *	" "	" "	" "	" "
7/82	2.0 – 2.5 4.0 – 4.5 11.0 – 11.5 13.0 – 13.5	*** *** *** ***	** N. D. Tr. Tr.	** ** *** *	*** ** * Tr.	** ** * **	* N. D. * *	* * * *	N. D. N. D. N.D. N.D.
16/82	2.0 – 2.5 4.0 – 4.5 5.0 – 5.5 6.0 – 6.5	*** *** *** ***	** * * *	** * * **	* * Tr Tr	** * * *	N. D. * N. D. N. D.	* * * N. D.	N. D. N. D. N. D. *
15/82	2.0 – 3.5 7.5 – 8.0 9.5 – 10.0	*** *** ***	* Tr *	** ** *	* Tr *	** * *	* * N.D.	N.D. N.D. *	N. D. N. D. N. D.
17/82	3.0 – 3.5 4.0 – 4.5 5.0 – 5.5 6.0 – 6.5	*** *** * ***	* * * **	** ** ** **	* * * *	* ** ** *	* N.D. * *	N.D. * * N.D.	N. D. N. D. N. D. Tr.

N.M. Not Measured
N.D. Not detected
Relative X-ray intensities:
*** Strong
** Medium
* Weak
Tr Trace

Table 1. Mineralogical composition (general) of samples from the Nicosia Marl, carried out at B.G.S.

BH No	(m) Sample Depth	Total carbonate (%)	Quartz (%)	Ca-montmor. (%)
EG 8/82	2.0 – 2.5	26	8	19(150)
	4.0 – 4.5	36	6	17(136)
	5.0 – 5.5	32	6	20(158)
EG 9/82	3.5 – 4.0	32	4	31(251)
EG 14/82	2.0 – 2.5	32	5	24(193)
	6.0 – 6.5	39	7	14(114)
	9.5 – 10.0	24	8	24(192)
	11.0 – 11.5	32	6	18(140)
EG 18/82	3.0 – 3.5	45	5	24(189)
	11.0 – 11.5	38	8	22(179)
EG 16/82	2.0 – 2.5	20	9	22(179)
	4.0 – 4.5	21	9	21(168)
	11.0 – 11.5	30	11	16(131)
	13.0 – 13.5	29	4	19(149)
EG 16/82	2.0 – 2.5	33	6	25(195)
	4.0 – 4.5	45	5	16(126)
	5.0 – 5.5	55	5	10(84)
	6.0 – 6.5	58	6	11(86)
EG 15/82	3.0 – 3.5	35	7	28(222)
	7.5 – 8.0	55	6	15(122)
	9.5 – 10.0	54	5	13(96)
EG 17/82	3.0 – 3.5	41	7	16(128)
	4.0 – 4.5	29	9	21(180)
	5.0 – 5.5	25	6	24(190)
	6.0 – 6.5	44	7	14(115)

Figures in brackets are Surface Areas in m^2/g.

Table 2. Total carbonate, quartz and Ca-montmorillonite contents of samples from the Nicosia Marl, carried out at B.G.S.

NICOSIA MARLS, BG.S. SWELLING PRESSURE TEST DATA

SAMPLE B/H	SITE	DEPTH in m	SWELL PRESSURE in KPa	MOISTURE CONTENT In %			BULK DENSITY g/cc		DRY DENSITY g/cc
				PRETEST	POSTTEST	SHAVINGS	PRETEST	POSTTEST	
7/82	MAKEDONITISSA	2.0 — 2.5	16.06	34.14	35.76	30.86	1.853	1.876	1.382
		4.0 — 4.5	X	—	—	31.45	—	—	—
		11.0 — 11.5	3.68	30.77	35.20	31.36	1.802	1.863	1.378
		13.0 — 13.5	X	—	—	33.48	—	—	—
8/82	EKTHESI	2.0 — 2.5	33.73	30.83	30.98	29.41	1.933	1.955	1.493
		3.0 — 3.5	X	—	—	24.03	—	—	—
		4.0 — 4.5	8.03	34.82	35.71	34.24	1.760	1.772	1.306
		5.0 — 5.5	20.08	35.84	37.32	34.47	1.832	1.852	1.350
9/82	ANTHOUPOLIS	3.5 — 4.0	X	—	—	28.90	—	—	—
14/82	LYKAVITOS	2.0 — 2.5	40.81	30.26	31.80	28.56	1.924	1.947	1.477
		3.0 — 3.5	X	—	—	29.66	—	—	—
		4.0 — 4.5	X	—	—	33.40	—	—	—
		5.0 — 5.5	17.82	27.75	30.07	28.89	1.901	1.936	1.488
		6.0 — 6.5	16.00	30.50	32.72	29.53	1.843	1.874	1.412
		7.5 — 8.0	77.49	37.72	39.50	34.80	1.862	1.886	1.352
		9.5 — 10.0	51.39	41.00	42.50	39.62	1.811	1.820	1.280
		11.0 — 11.5	29.31	33.56	34.87	—	1.874	1.892	1.403
15/82	PRODUCTIVITY CENTRE	3.0 — 3.5	X	—	—	31.05	—	—	—
		7.5 — 8.0	X	—	—	31.00	—	—	—
		9.5 — 10.0	X	—	—	28.77	—	—	—
16/82	EYLENJA	2.0 — 2.5	X	—	—	24.94	—	—	—
		4.0 — 4.5	X	—	—	17.35	—	—	—
		5.0 — 5.5	16.46	23.41	29.25	25.27	1.645	1.720	1.330
		6.0 — 6.5	14.86	22.56	23.94	21.19	1.826	1.847	1.490
17/82	AYIOS NICOLAOS	3.0 — 3.5	14.69	27.18	28.81	29.60	1.922	1.947	1.510
		4.0 — 4.5	39.56	34.26	35.50	36.48	1.876	1.894	1.400
		5.0 — 5.5	37.74	34.40	35.98	35.40	1.849	1.871	1.380
		6.0 — 6.5	22.08	26.63	27.44	26.70	1.986	2.001	1.570
18/82	AYIA VARVARA	3.0 — 3.5	68.66	23.80	24.56	(25.60?)	1.884	1.895	1.520
		5.0 — 5.5	55.97	32.78	35.45	34.03	1.861	1.899	1.400
		7.5 — 8.0	X	—	—	29.59	—	—	—
		11.0 — 11.5	35.16	32.27	34.02	29.05	1.884	1.908	1.420

G.S.D.(E.Geol.)D.P. 30/83

X—SAMPLE PREPARATION UNSUCCESSFUL

NICOSIA MARLS
DERIVED CONSOLIDATION DATA

□ G.S.D. Test
* BG.S. Test

BH. No	DEPTH (m)	NAT M/C (%)	eo	Po' (estimtd) (KPa)	Psw' (KPa)	Cc LAB.	Cc FIELD	Gs	Pc' Min Prob	Pc' Max Prob	Pc' Most Prob	O.C.R. Min Prob.	O.C.R. Max Prob	O.C.R. Most Prob
EG 7/82*	2·0–2·5		0·542	19	16·1	0.12	0·12	0·032	150	700	310	7·9	36·8	16·3
EG 8/82□*	4·0–4·5	32·9* 32·9□	0·920* 0·922□	37* 37□	8·0* 14·5□	0·166* 0·273□	0·176* 0·283□	0·037* 0·056□	150* 860□	680* 1300□	250* 1020□	4·1* 23·2□	18·4* 35·1□	6·8* 28·0□
EG 8/82□	5·0–5·5	37·1	0·986	94	22·5	0·365	0·408	0·081	610	1400	900	6·5	14·9	9·5
EG14/82□	2·0–2·5	29·7	0·862	46	87·0	0·174	——	0·069	320?	1300	600	7·0?	28·3	13·2
EG14/82□	3·0–3·5	29·4	0·782	61	56·0	0·160	——	0·063	370	1500	760	6·1?	48·4	12·6
EG14/82□	4·0–4·5	31·0	0·917	80	17·0	0·240	0·240	0·049	600	1400	650	7·5	17·5	8·1
EG14/82□	5·0–5·5	33·0	0·879	100	37·0	0·319	0·354	0·059	750	1500	1120	7·5	15·0	11·2
EG14/82□	7·5–8·0	36·5	0·940	145	170·0	0·258	——	0·091	570?	1200	870	3·9	8·3	6·1
EG14/82□*	9·5–10·0	39·5	1·000* 1·120□	165* 165□	51·4* 56·0□	0·350* 0·360□	0·384* 0·360□	0·075* 0·106□	160* 840□	600* 1250□	260* 840□	1·0* 5·3□	3·6* 7·6□	1·6* 5·3□
EG14/82□	11·0–11·5	35·3	0·906	135	70·0	0·210	0·212	0·060	1070	1600	1200	7·9	11·9	8·9
EG 15/82□	7·0–7·5	36·0	1·108	105	10·5	0·456	0·500	0·057	750	1700	1030	7·1	16·2	9·5
EG 15/82□	9·5–10·0	31·0	0·885	125	23·0	0·292	0·324	0·06	640	1900	1000	5·1	15·2	8·2
EG 16/82□	5·0–5·5	21·0	1·107	87	11·2	0·476	0·526	0075	450	1400	580	5·2	16·1	6·6
EG 16/82□*	6·0–6·5	26·5	0·725□	45□	18·5□	0·233□	0·283□	0·048□	280□	1600□	650□	6·2□	35·6□	14·4□
EG17/82□	3·0–3·5	31·5	0·765	52	28·0	0·135	0·135	0·066	260?	800	300	5·0?	15·4	5·6
EG17/82□	4·0–4·5	35·0	0·883	65	17·5	0·226	0·226	0·084	160?	360	175	2.5	5·5	2·7
EG17/82□	5·0–5·5	35·0	0·982	75	21·5	0·295	0·295	0·166	500?	1200	530	6·7?	16·0	7·2
EG18/82*	3·0–3·5	28·0	0·724	——	68·7	0·120	——	0·044	——	——	——	——	——	——
EG 18/82□	7·5–8·0	28·0	0·783	105	28	0·193	0·202	0·064	255	1000	360	2·4	9·5	3·4

G.S.D. (E.Geol.) D.P. 21/83

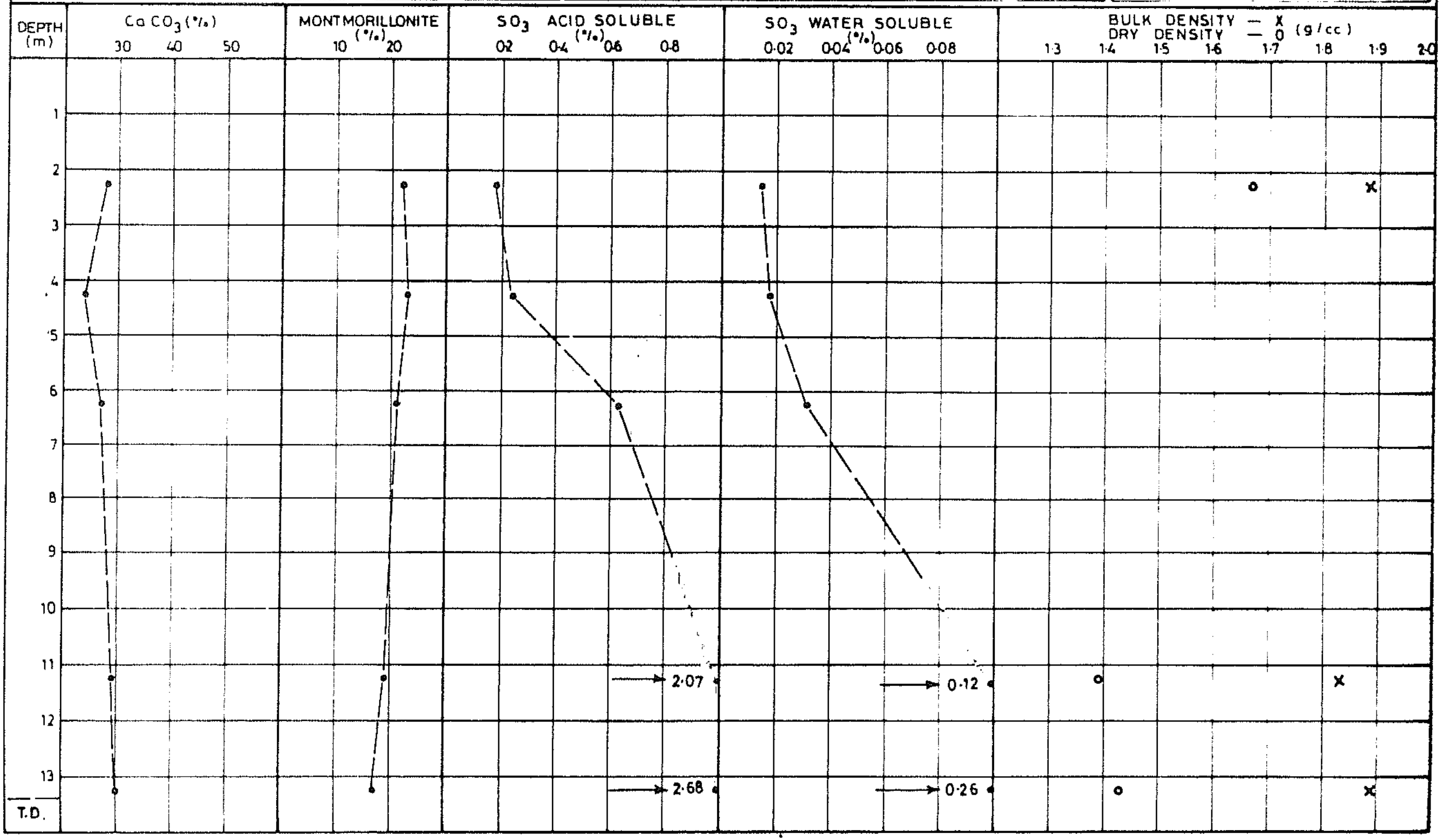
APPENDIX 2

NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH. No EG 7/82

SITE MAKEDHONITISSA
GRID REF: 5 284 25 E , 3889130 N G/L 187 m W/T 7·2 m

DATE 12/5/82



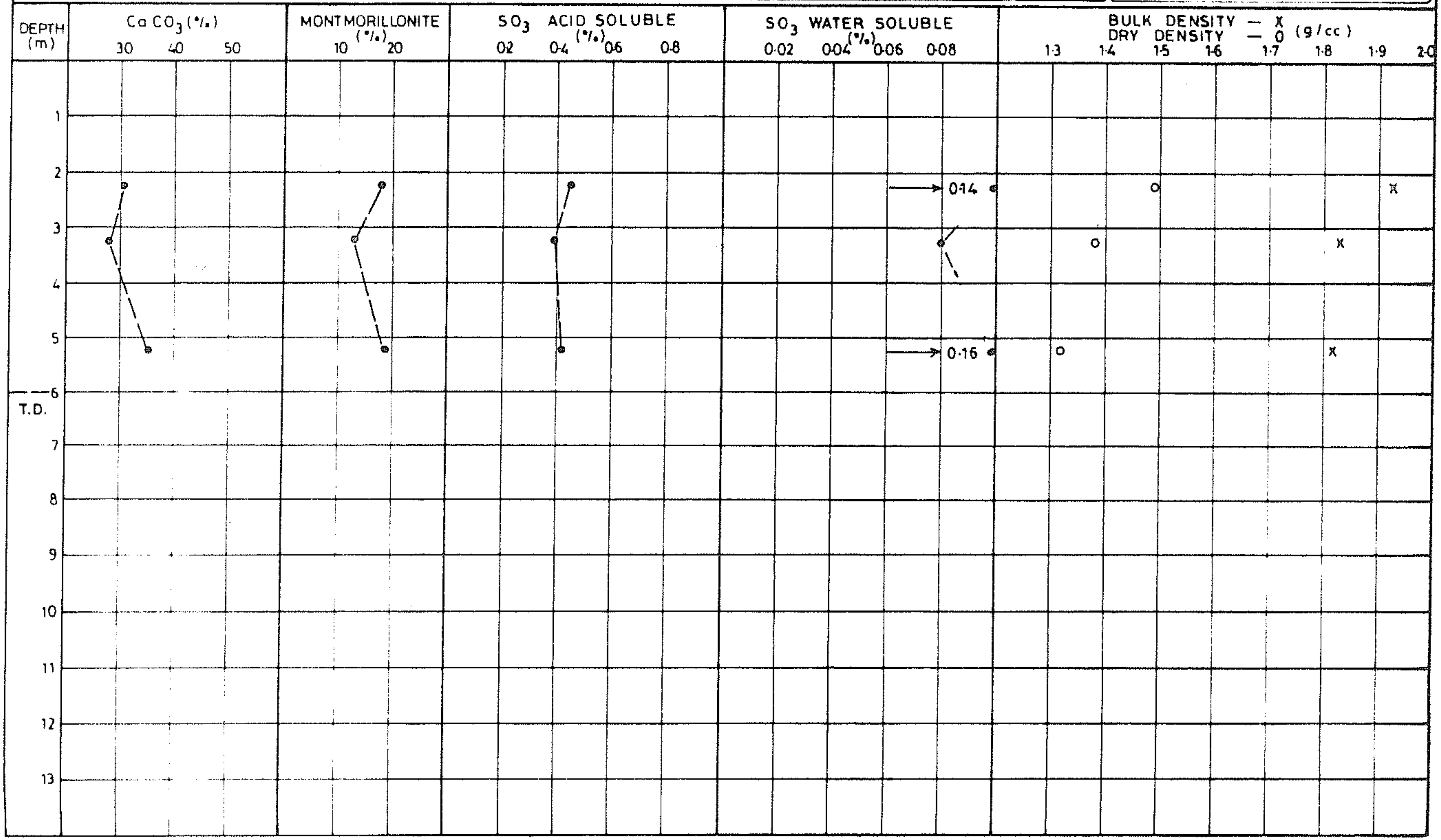
APP. 2.1

NICOSIA COHESIVE SOILS : Variation of $CaCO_3$, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No. EG 8/82

SITE NATIONAL EXHIBITION CENTRE
GRID REF 5 288 80 E , 38 903 45 N G/L 173 m W/T DRY

DATE 19/5/82



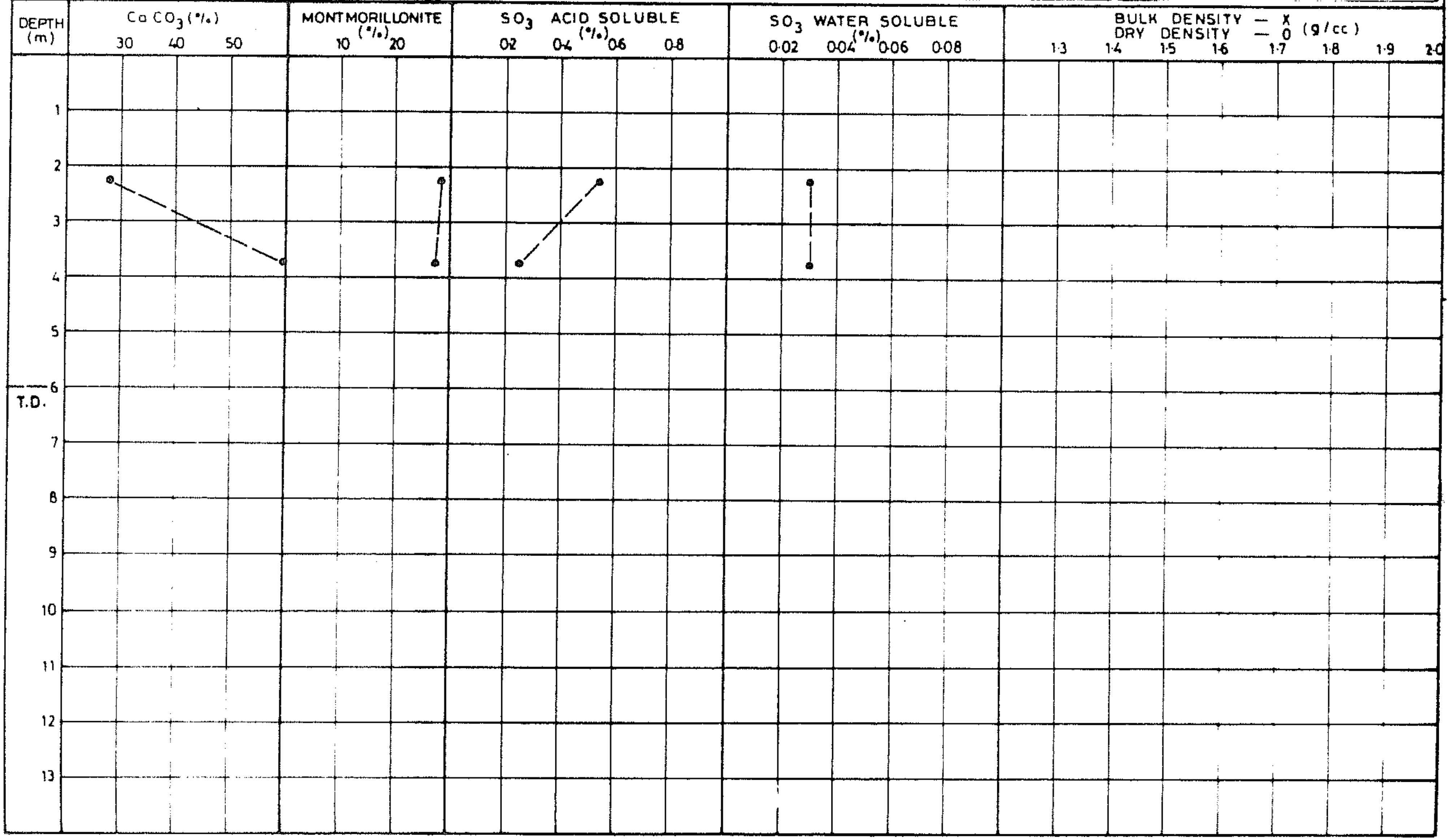
APP. 2.1

NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No. EG 9/82

SITE ANTHOUPOLIS
GRID REF. 526993 E, 3886915 N G/L 230 m W/T DRY

DATE 20/5/82



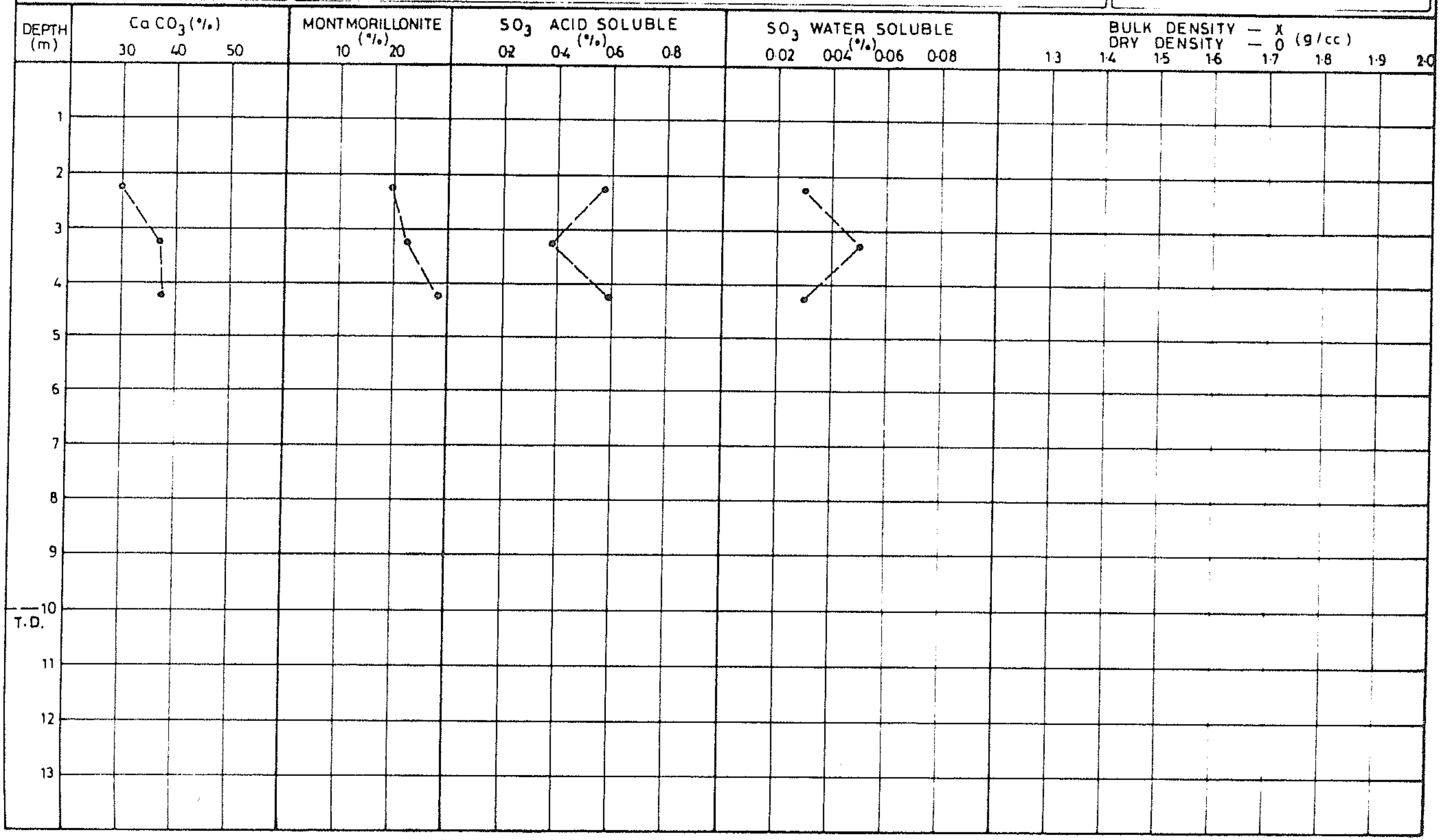
APP. 2.1

NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No. EG 13/82

SITE ANTHOUPOLIS
GRID REF: 5 26118 E , 38 86115 N G/L 248 m W/T DRY

DATE 7/6/82



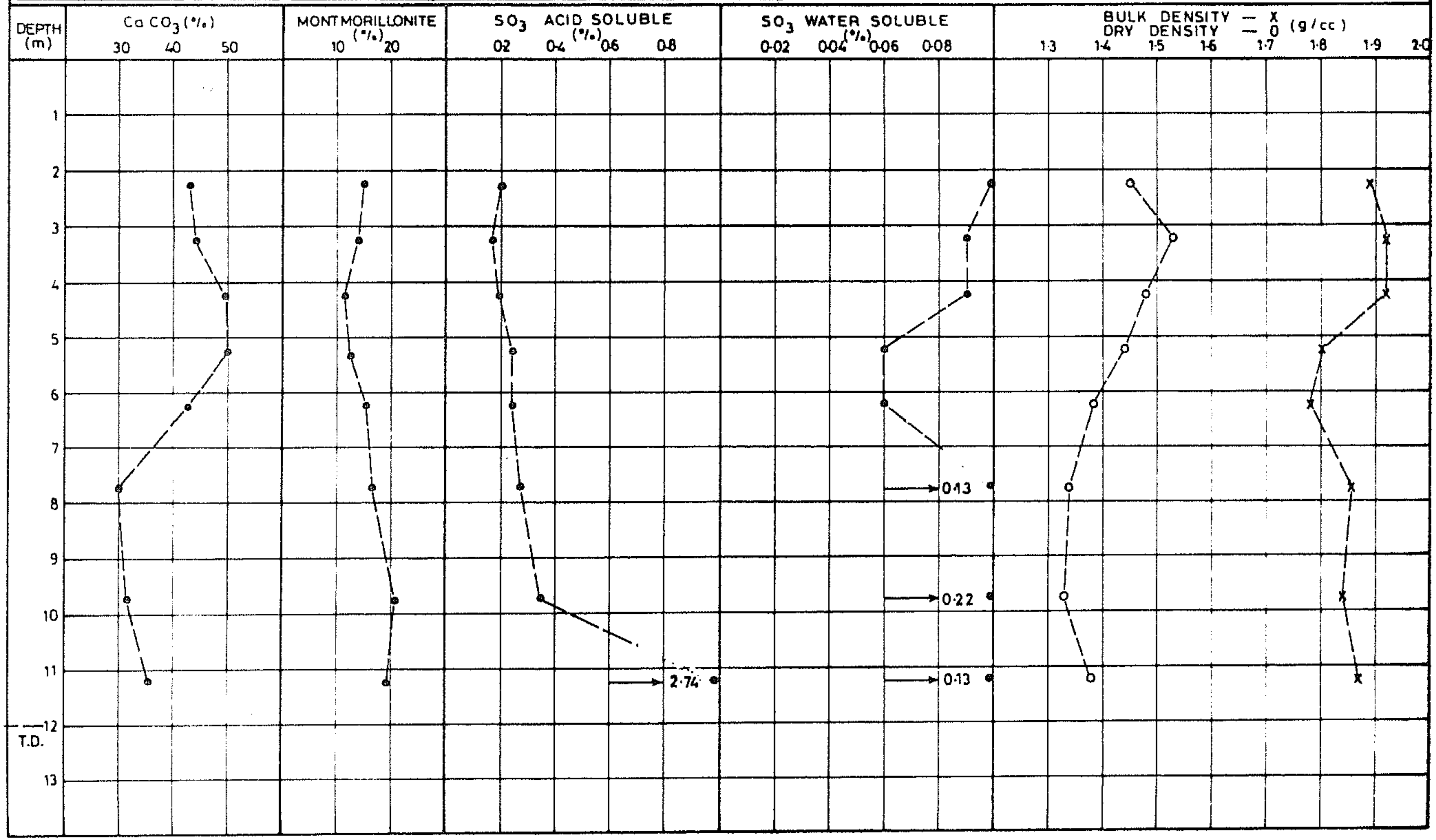
APP. 2.1

NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH. No.: EG 14/82

SITE : LYKAVITOS SCHOOL
GRID REF: 533715 E, 3891310 N G/L 146 m W/T 3·5→4·7

DATE 10/6/82

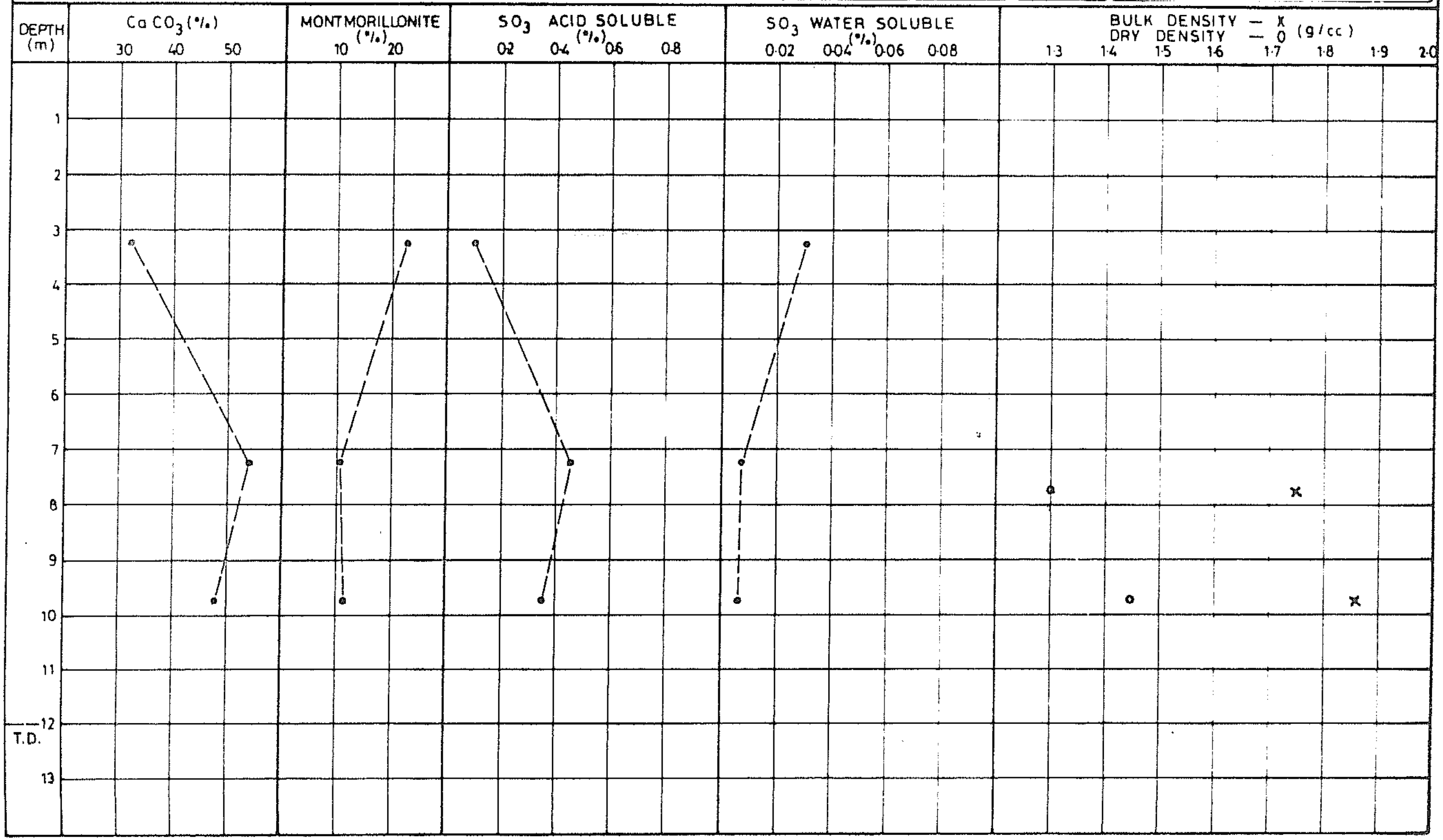


NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH. No.: EG 15/82

SITE: PRODUCTIVITY CENTRE
GRID REF: 534305 E, 3890845 N G/L 159 m W/T 5·30 m

DATE 17/6/82



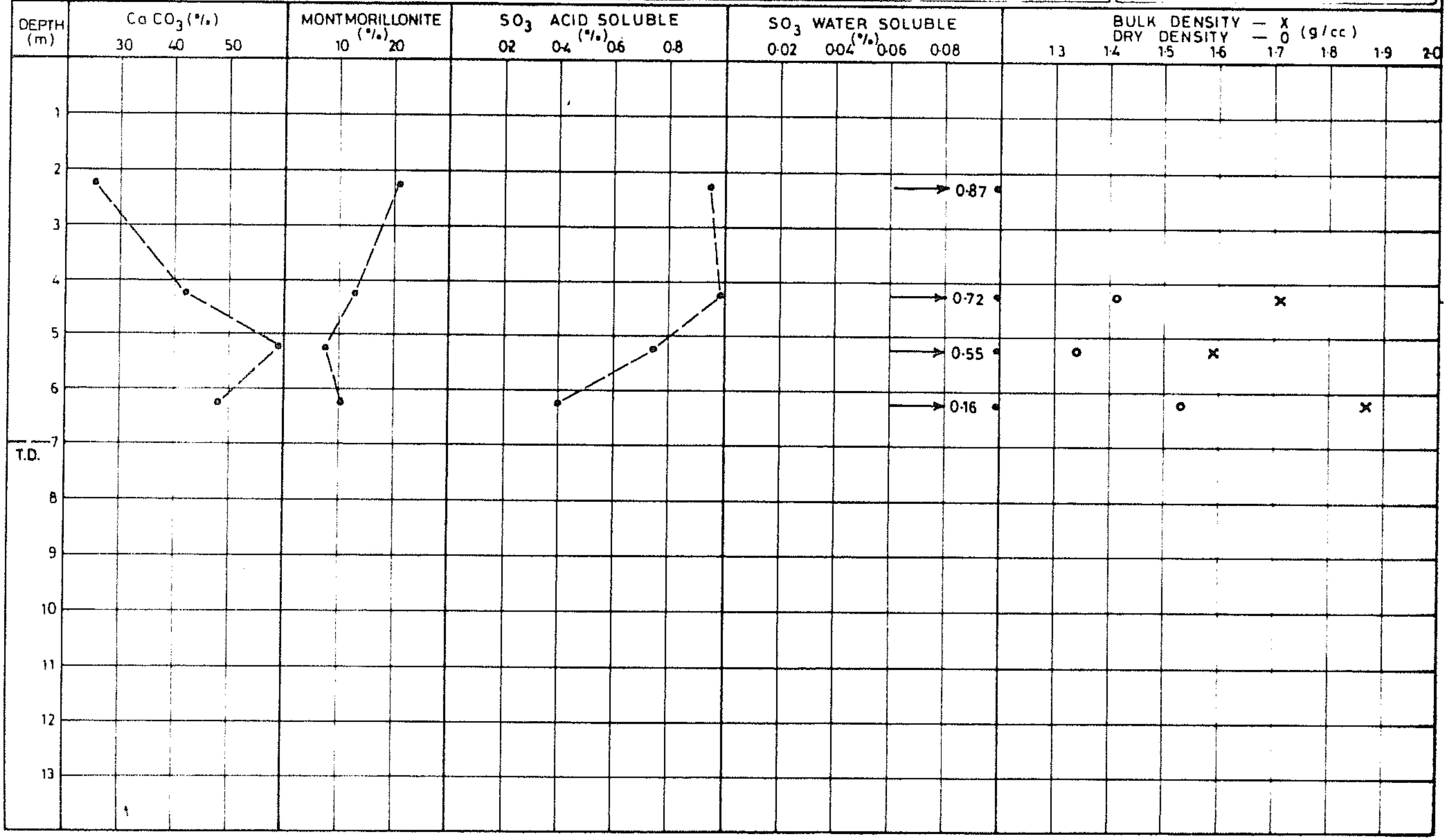
APP. 2,1

NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No EG 16/82

SITE EYLENJA
GRID REF: 535830E,3890443 N G/L 138 m W/T DRY

DATE 24/6/82



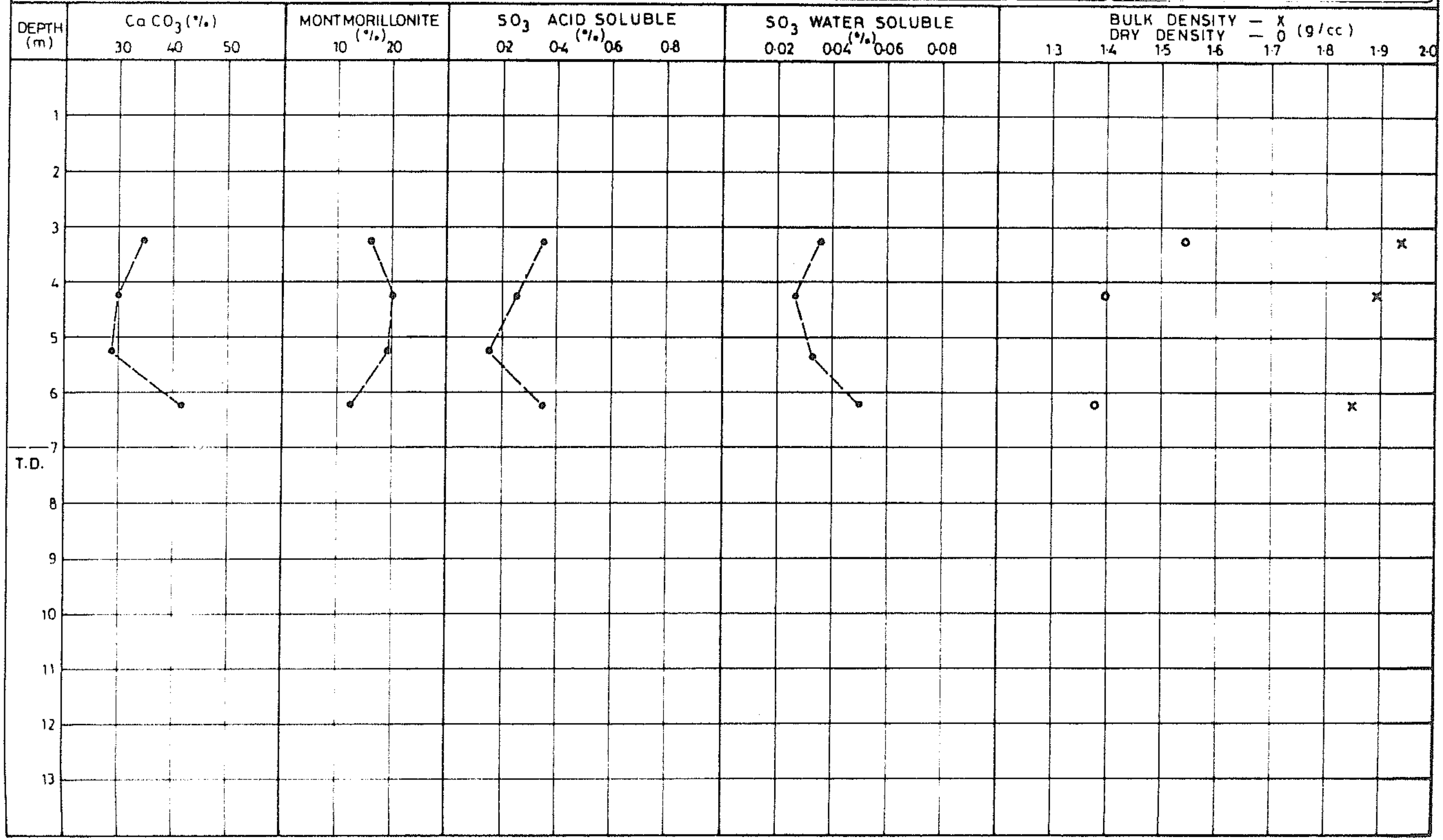
APP. 2.1

NICOSIA COHESIVE SOILS : Variation of Ca CO_3, MONTMORILLONITE, SO_3, BULK AND DRY DENSITIES WITH DEPTH

BH No. EG 17/82

SITE AYIOS NICOLAOS
GRID REF: s 35507 E, 3892870 N G/L 126 m W/T 1·4→1·7 m

DATE 29/6/82



APP. 2.1

PARTICLE SIZE DISTRIBUTION

Site: MAKEDONITISSA

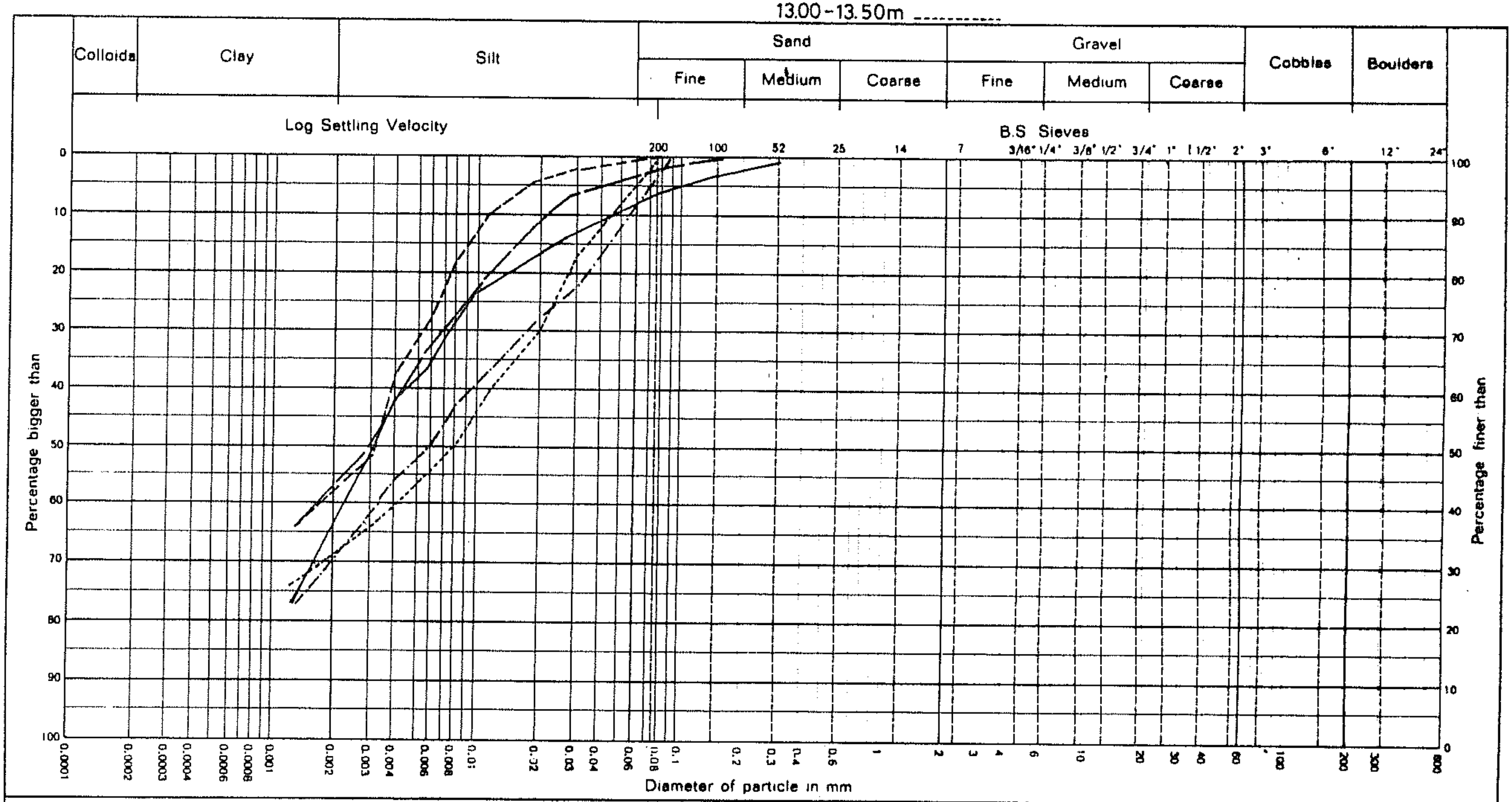
Operator: K. Solomis
A. Petrou

B.H. No.: EG./7/82

Depth: 2.00-2.50 m
4.00-4.50 m
6.00 - 6.50m
11.00-11.50m
13.00-13.50m

Date: 20/10/82

Description:



Note: According to British Standard

Lab. No.

G.S.D. (D.S.) 36

PARTICLE SIZE DISTRIBUTION

Site. EKTHESI

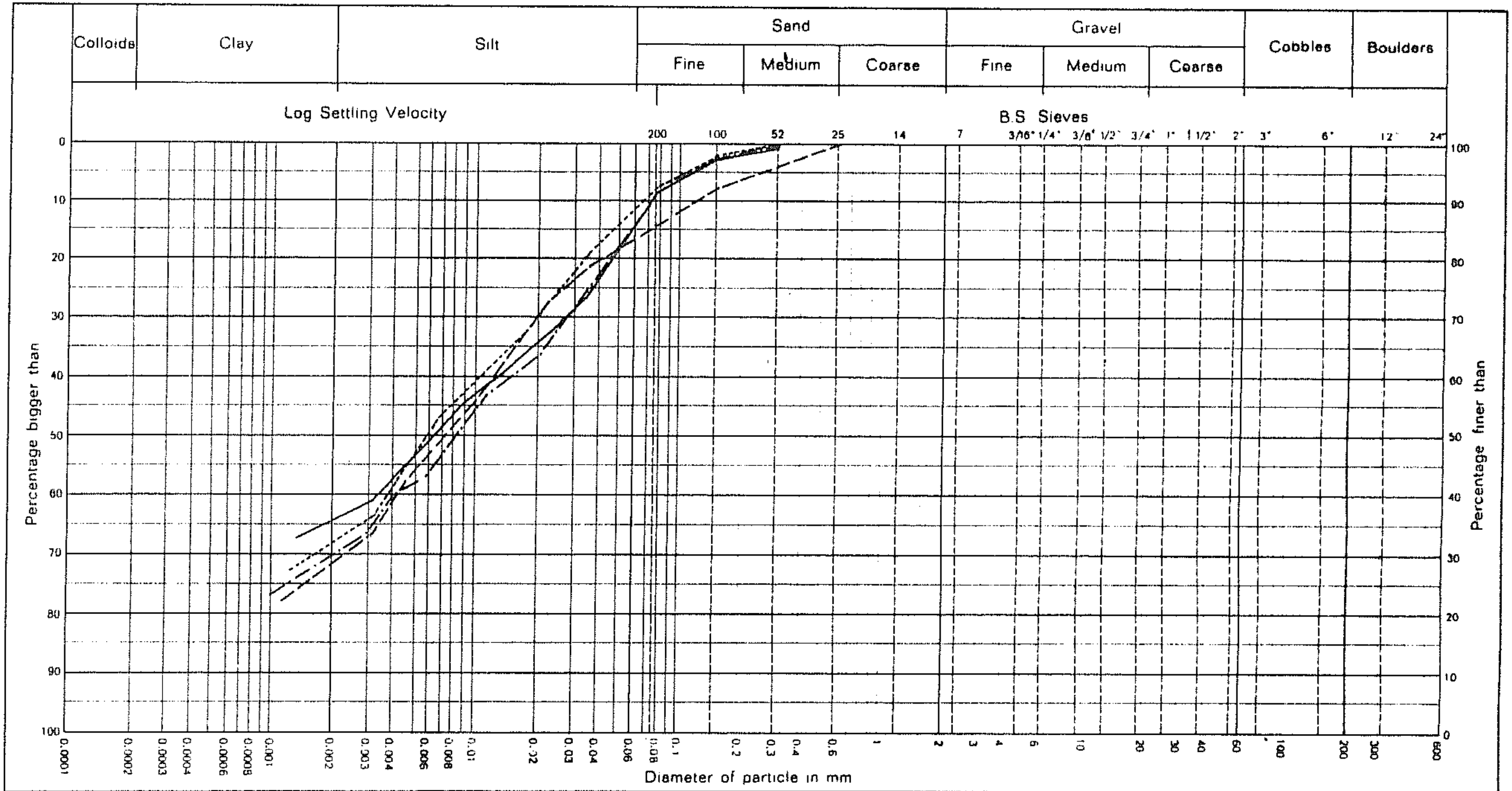
B.H. No.: EG/8/82

Depth 2.00 - 2.50 m ————
3.00 - 3.50 m — — — —
4.00 - 4.50 m —·—·—
5.00 - 5.50 m - - - - - - -

Date: 11/2/83

Operator: K. Solomis
A. Petrou

Description:



Note: According to British Standard

Lab. No.

GSD (DS) 36

APP. 2.2

PARTICLE SIZE DISTRIBUTION

Site: ANTHOUPOLIS

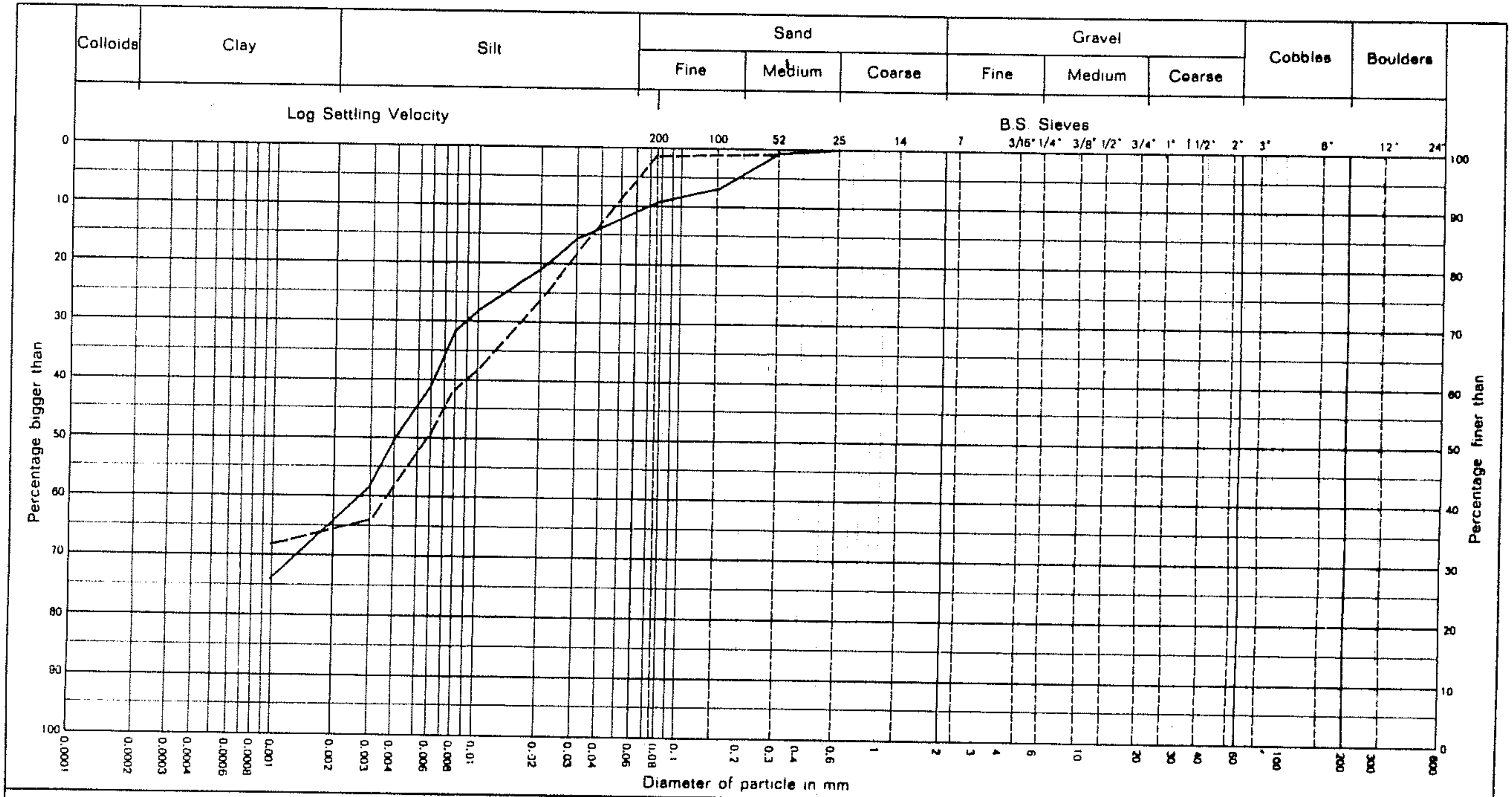
B.H. No.: EG/9/82

Depth: 2.00-2.50m ———
3.50-4.00m – – – –

Date: 8/2/83

Operator K. Solomis
A. Petrou

Description:



Note: According to British Standard

Lab. No.

G.S.D. (D.S.) 36

PARTICLE SIZE DISTRIBUTION

Site: ANTHOUPOLIS

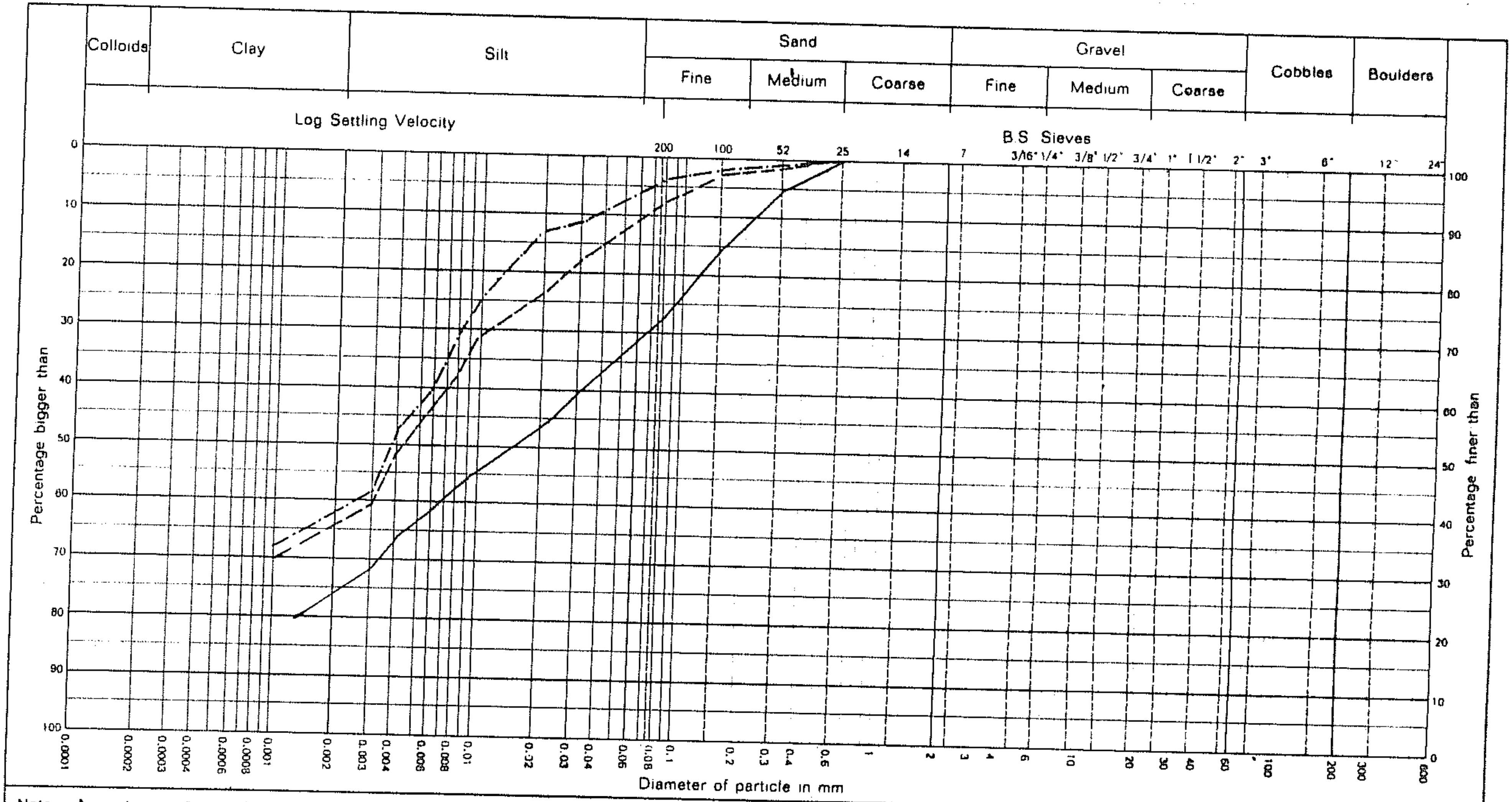
B.H. No.: EG/13/82

Depth: 2.00-2.50m ———
3.00-3.50m — — —
4.00-4.50m —·—·—

Date: 9/2/83

Operator K. Solomis
A. Petrou

Description:



Note: According to British Standard

Lab. No.

G.S.D. (D.S.) 36

APP. 2.2

PARTICLE SIZE DISTRIBUTION

Site: LYKAVITOS SCHOOL

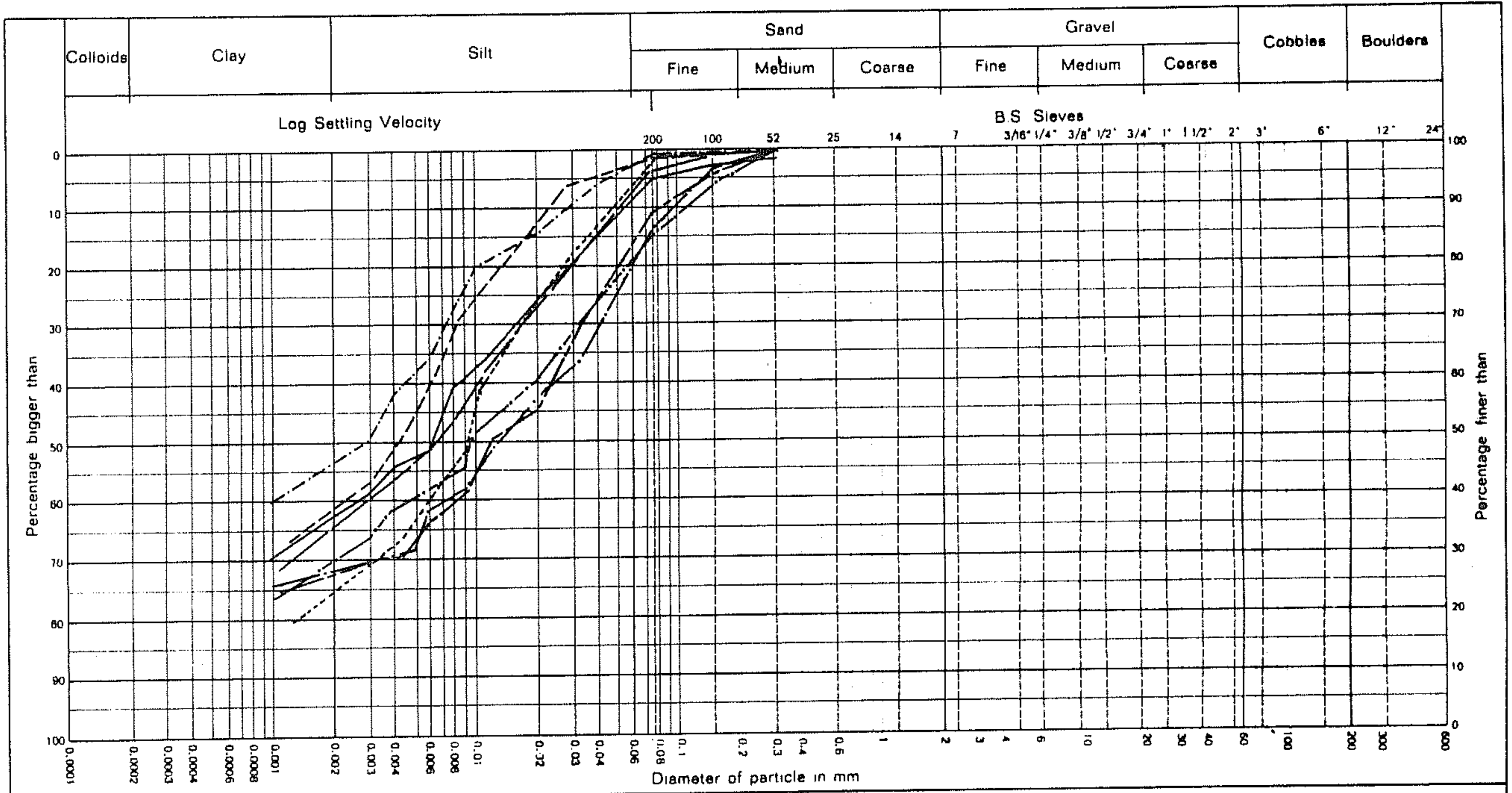
B.H. No.: EG/14/82

Operator: K.Solomis
A.Petrou

Depth:
2.00-2.50 m ————
3.00-3.50 m ————
4.00-4.50 m ——·——
5.00-5.50 m ——·-·——
6.00-6.50 m —— — —
7.50-8.00 m — — — —
9.50-10.00 m —·—·—·
11.00-11.50m - - - - - - - -

Date. 7/4/83

Description:



Note: According to British Standard

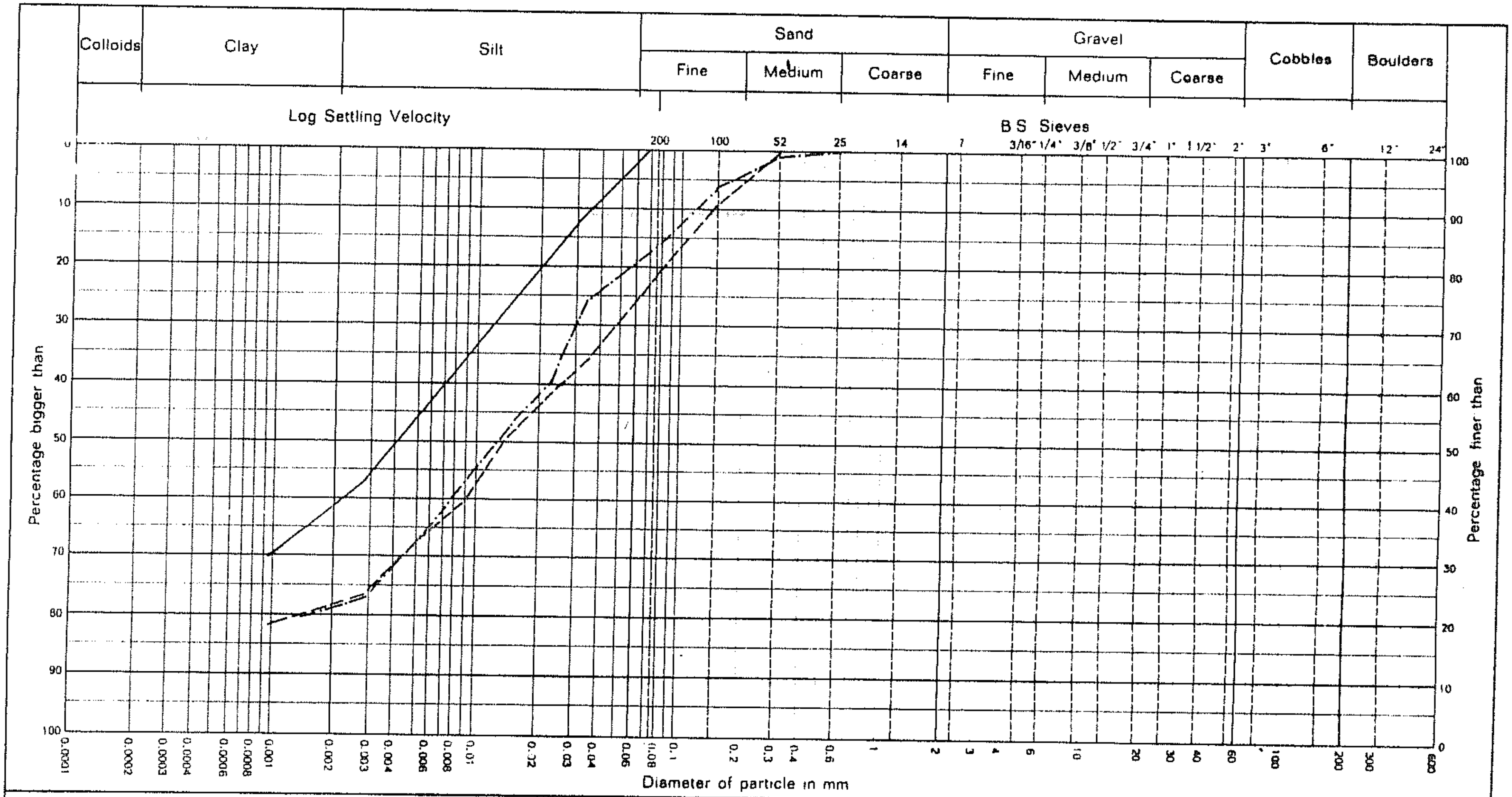
Lab. No.

G.S.D. (D.S) 36

PARTICLE SIZE DISTRIBUTION

Site: PRODUCTIVITY CENTRE   B.H. No.: EG/15 /82   Depth 3.00-3.50m
7.50-8.00m
9.50-10.00m   Date: 11/1/83

Operator: K. Solomis
A. Petrou   Description:



Note: According to British Standard

Lab. No.

G.S.D. (D.S.) 36

APP. 2.2

PARTICLE SIZE DISTRIBUTION

Site: AGLANTZIA

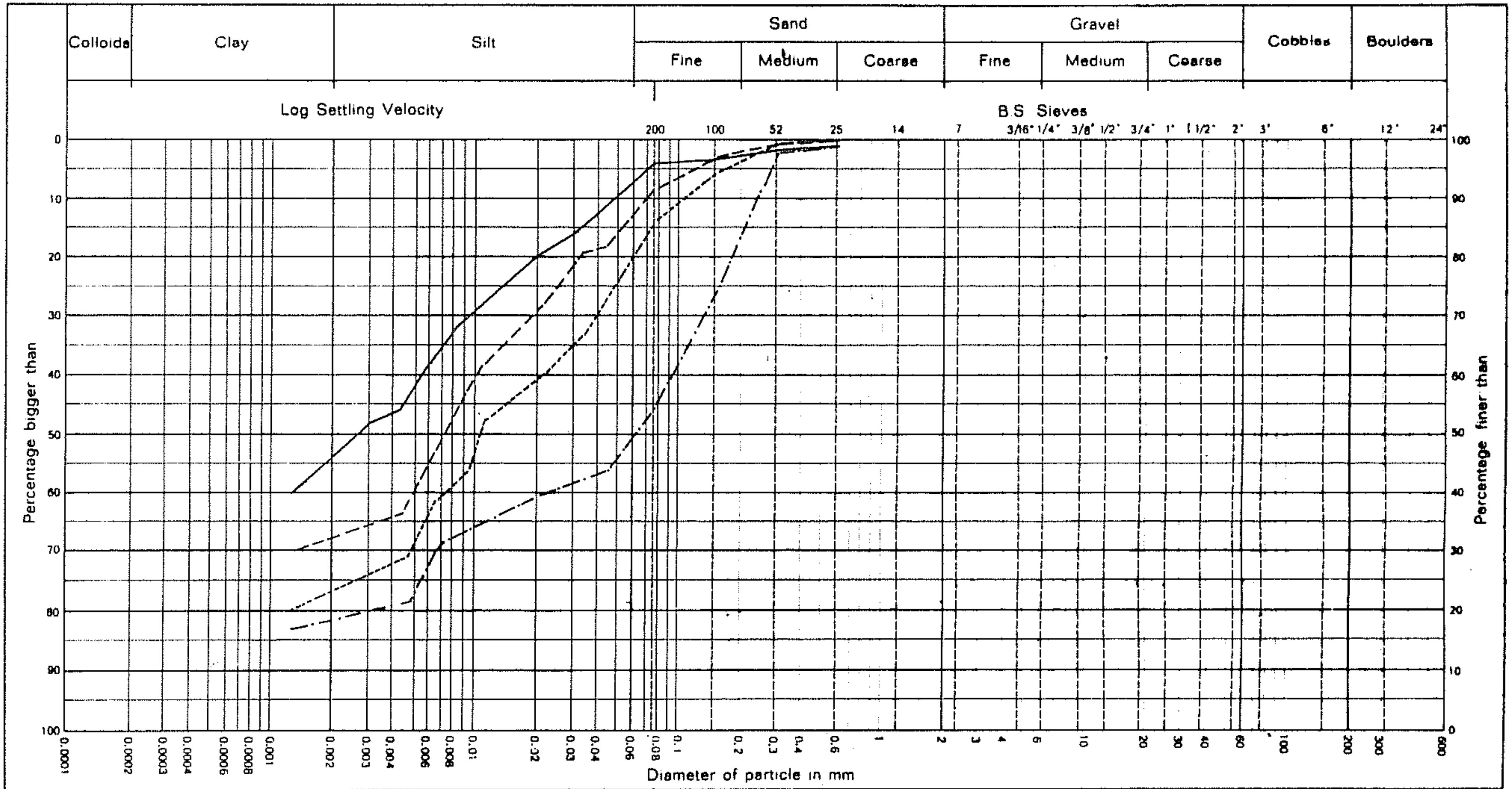
B.H. No.: EG/16/82

Depth: 2.00-2.50m ———
4.00-4.50m – – –
5.00-5.50m –·–·–
6.00-6.50m - - - - -

Date: 21/1/83

Operator: K. Solomis
A. Petrou

Description:



Note: According to British Standard

Lab. No.

G.S.D. (D.S.) 36

PARTICLE SIZE DISTRIBUTION

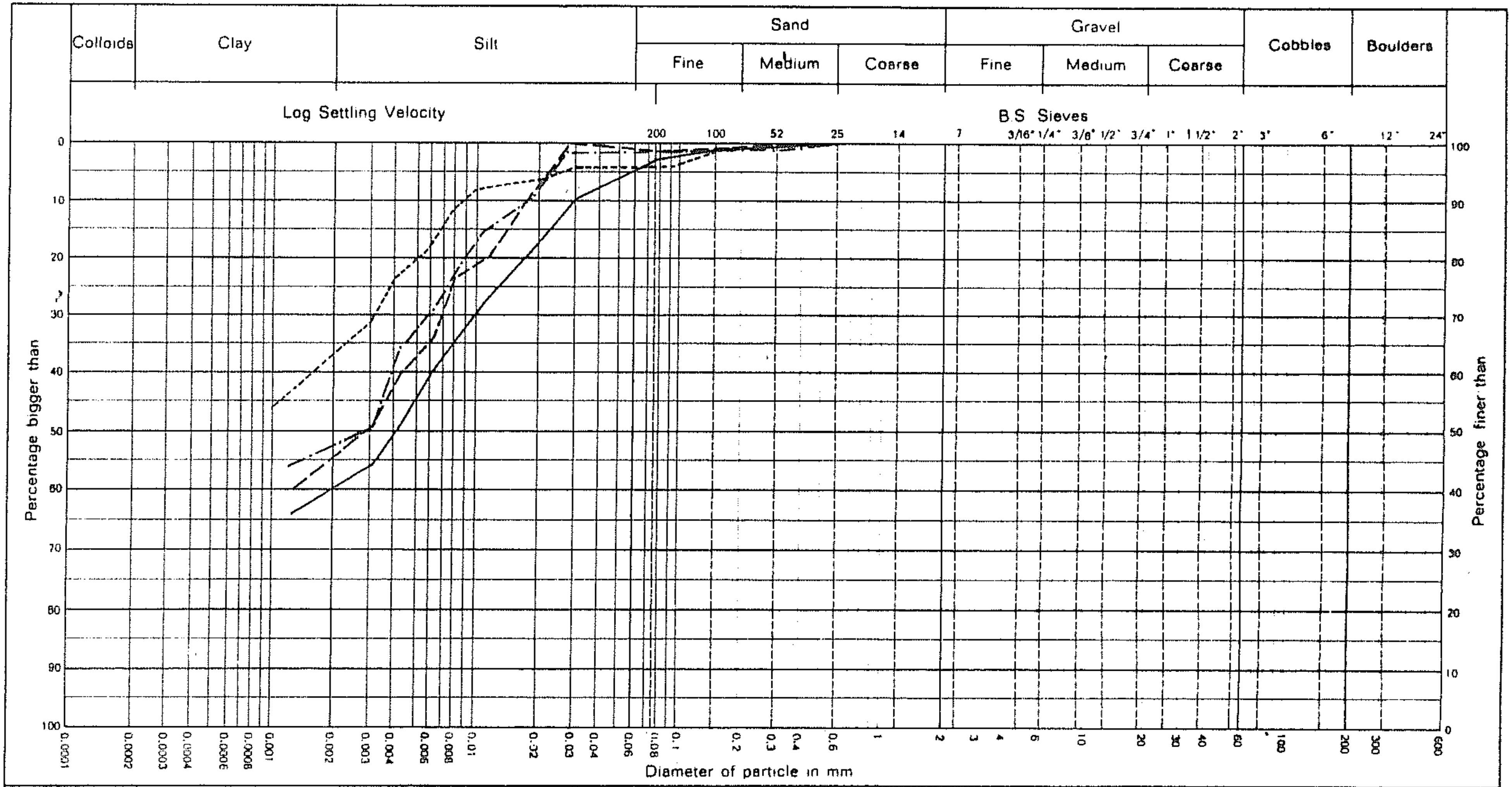
Site. AYIOS NIKOLAOS SETTLEM. B.H. No.: EG/17/82

Operator K. Solomis
A. Petrou

Depth. 3.00-3.50m ————
4.00-4.50m — — — —
5.00-5.50m —.—.—
6.00-6.50m - - - - - -

Description:

Date. 8/2/83



Note: According to British Standard

Lab. No.

G.S.D. (D.S.) 36

APP. 2.2

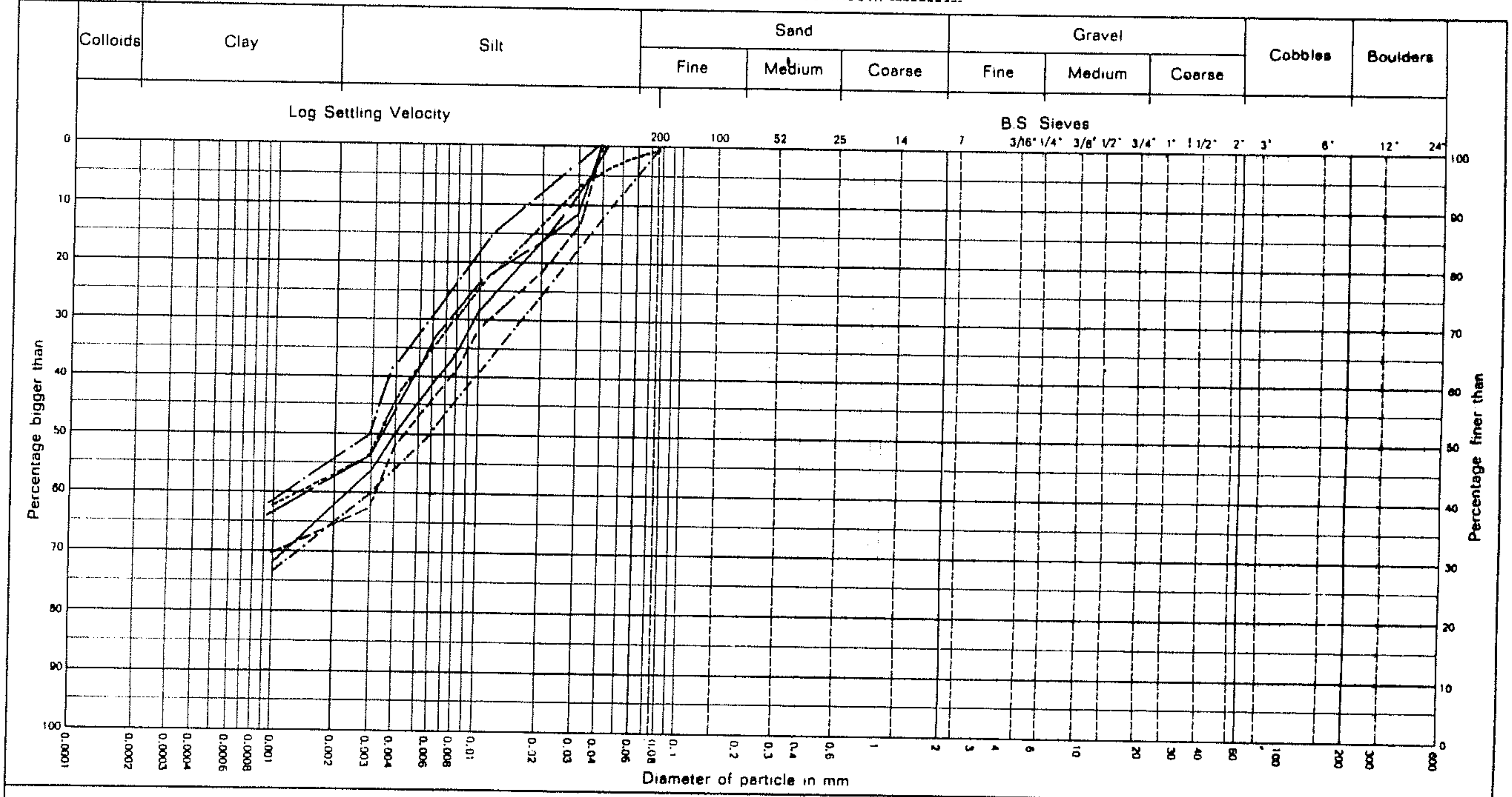
PARTICLE SIZE DISTRIBUTION

Site. AYIA VARVARA SETTLEMENT   B.H. No.. EG/18/82   Date: 9/3/83

Operator: K. Solomis
A. Petrou

Depth 3.00-3.50 m ————
4.00-4.50 m — — —
5.00-5.50 m —.—
7.50-8.00 m – – – –
9.50-10.00 m –.–.–
11.00-11.50 m - - - - -

Description:

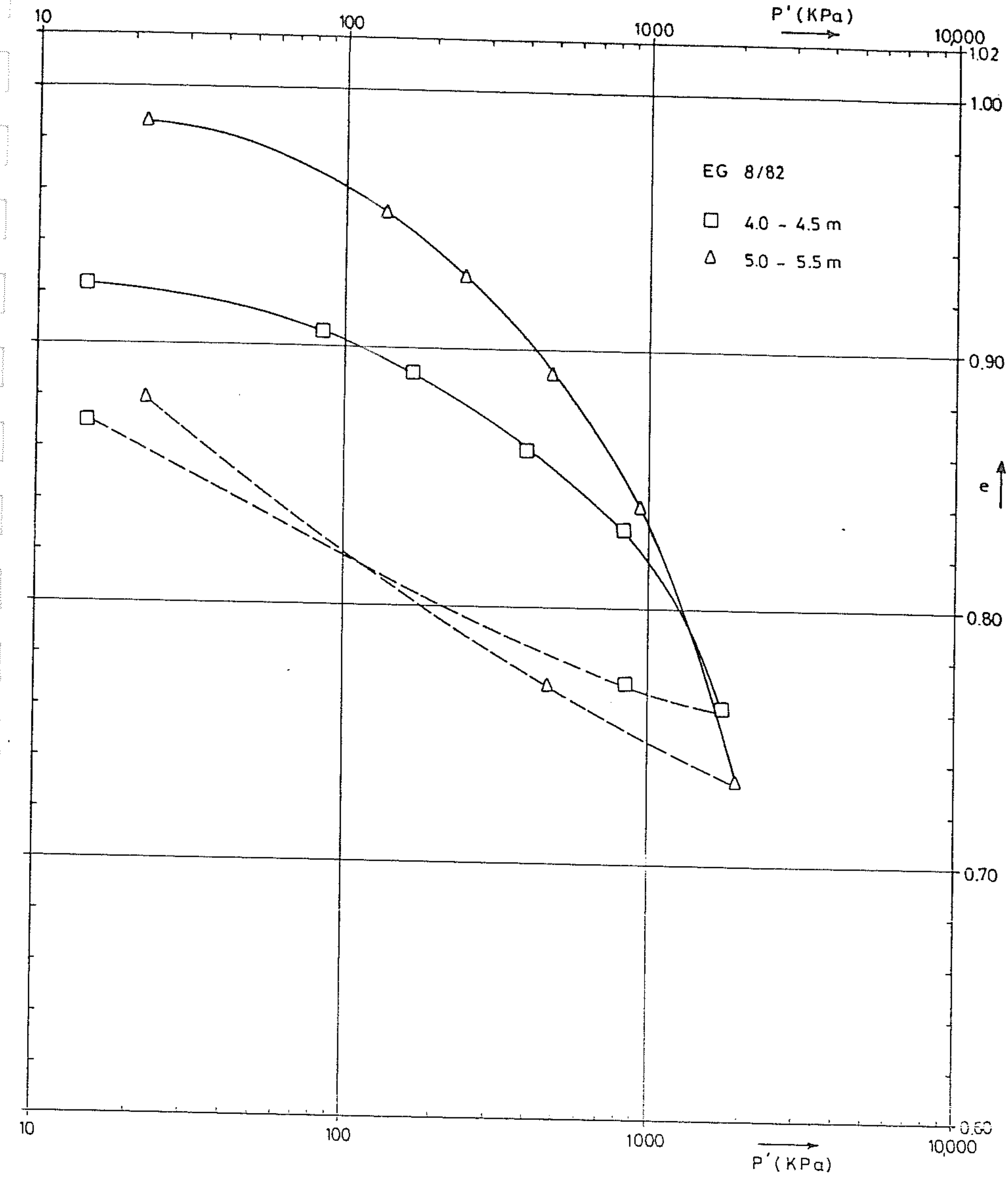


Note: According to British Standard

Lab. No.

G.S.D. (D.S.) 36

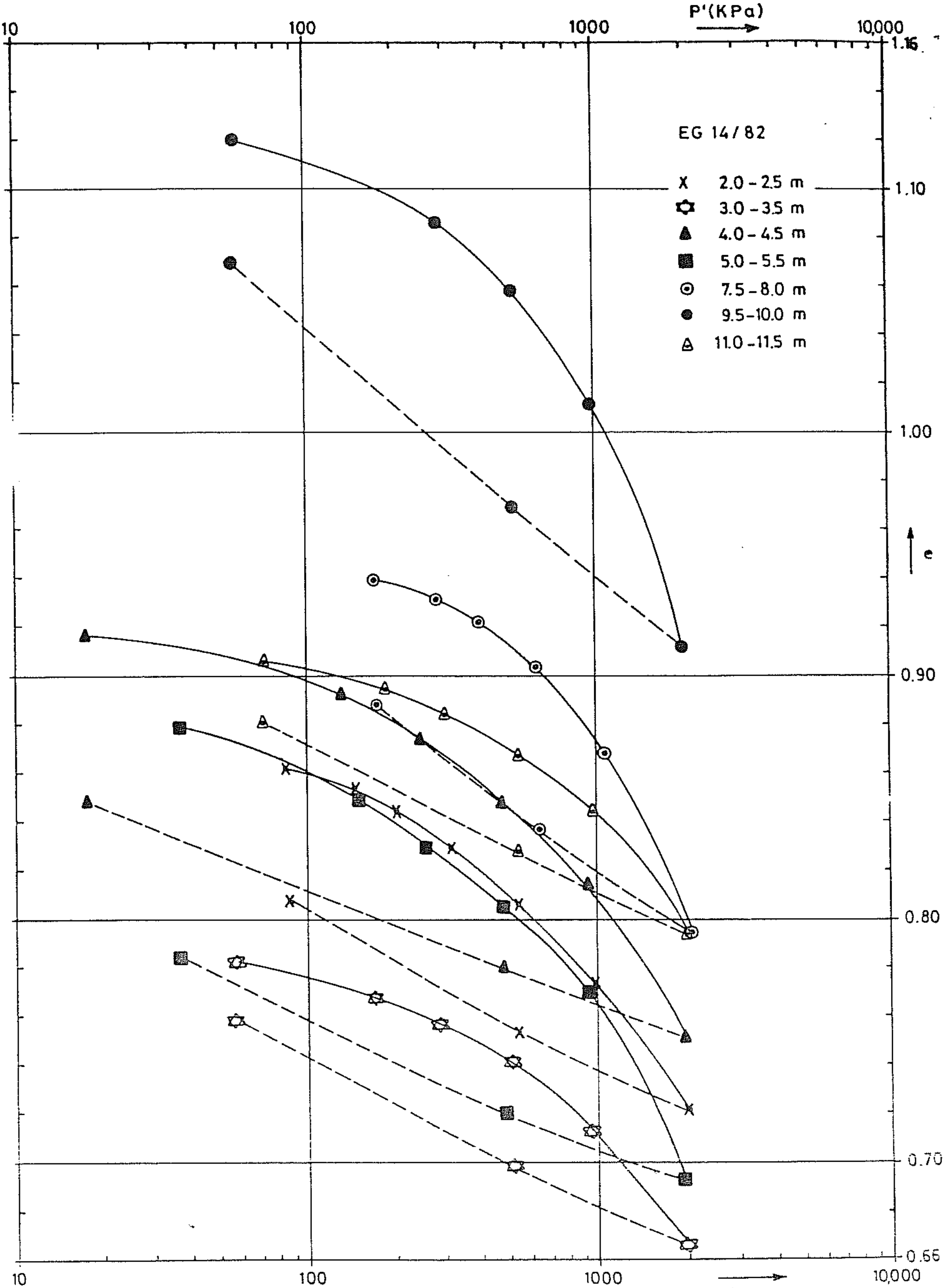
APP 22



OEDOMETER TEST CURVES (e - log P')

VOIDS RATIO v LOG PRESSURE

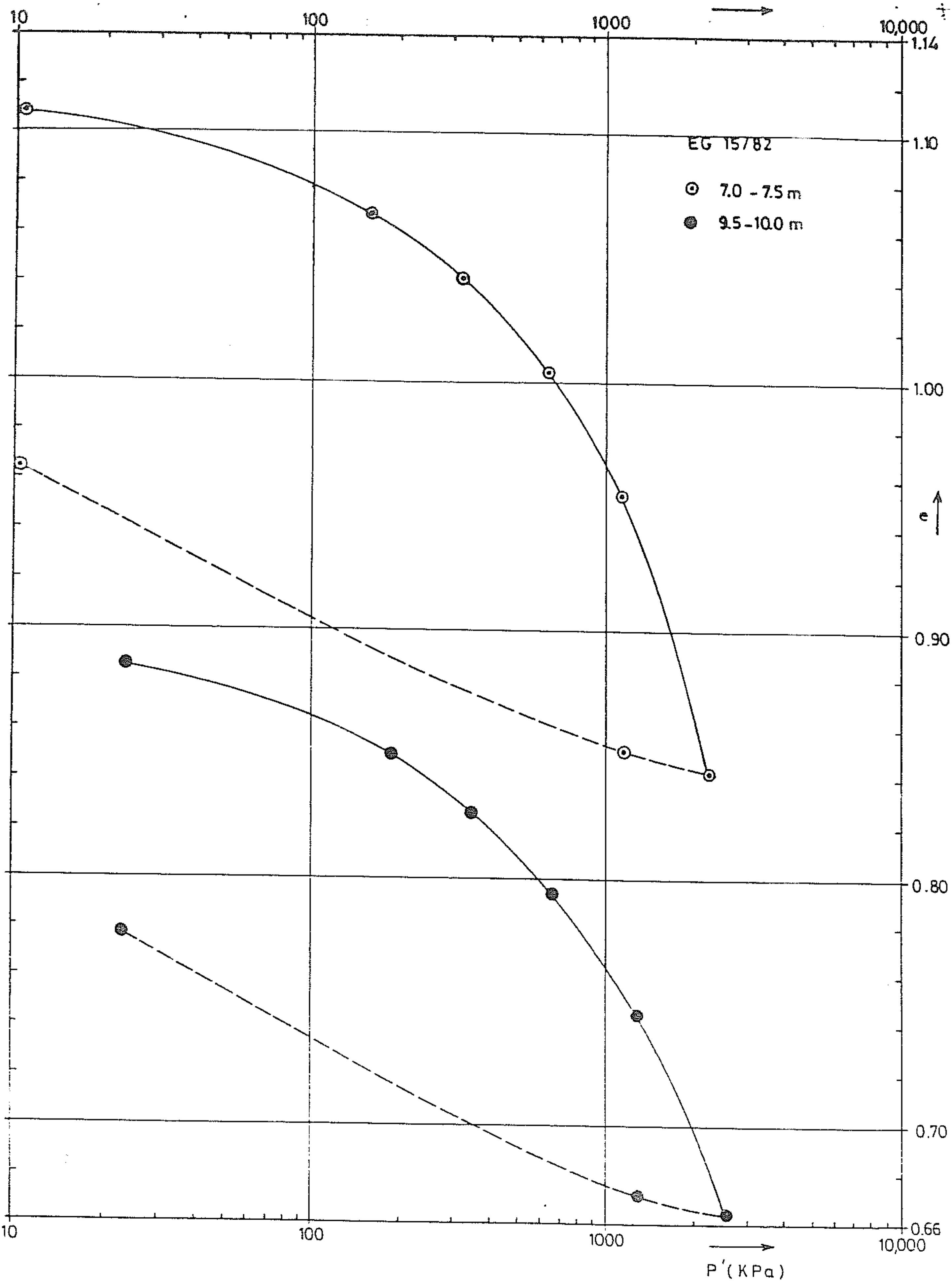
APP. 2.3



VOIDS RATIO v LOG PRESSURE

OEDOMETER TEST CURVES (e - log P')

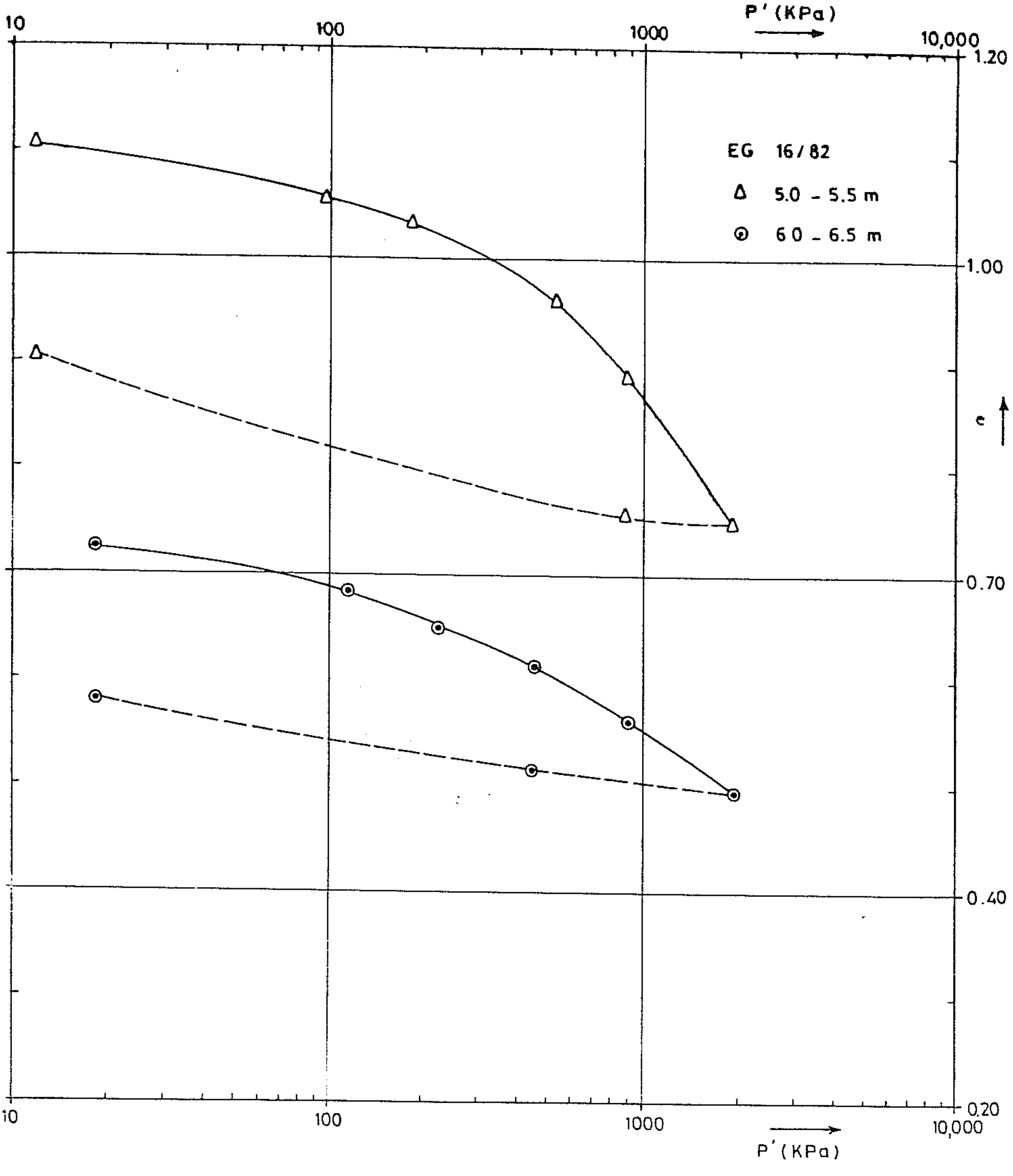
APP. 2.3



VOIDS RATIO v LOG PRESSURE

OEDOMETER TEST CURVES (e -log P')

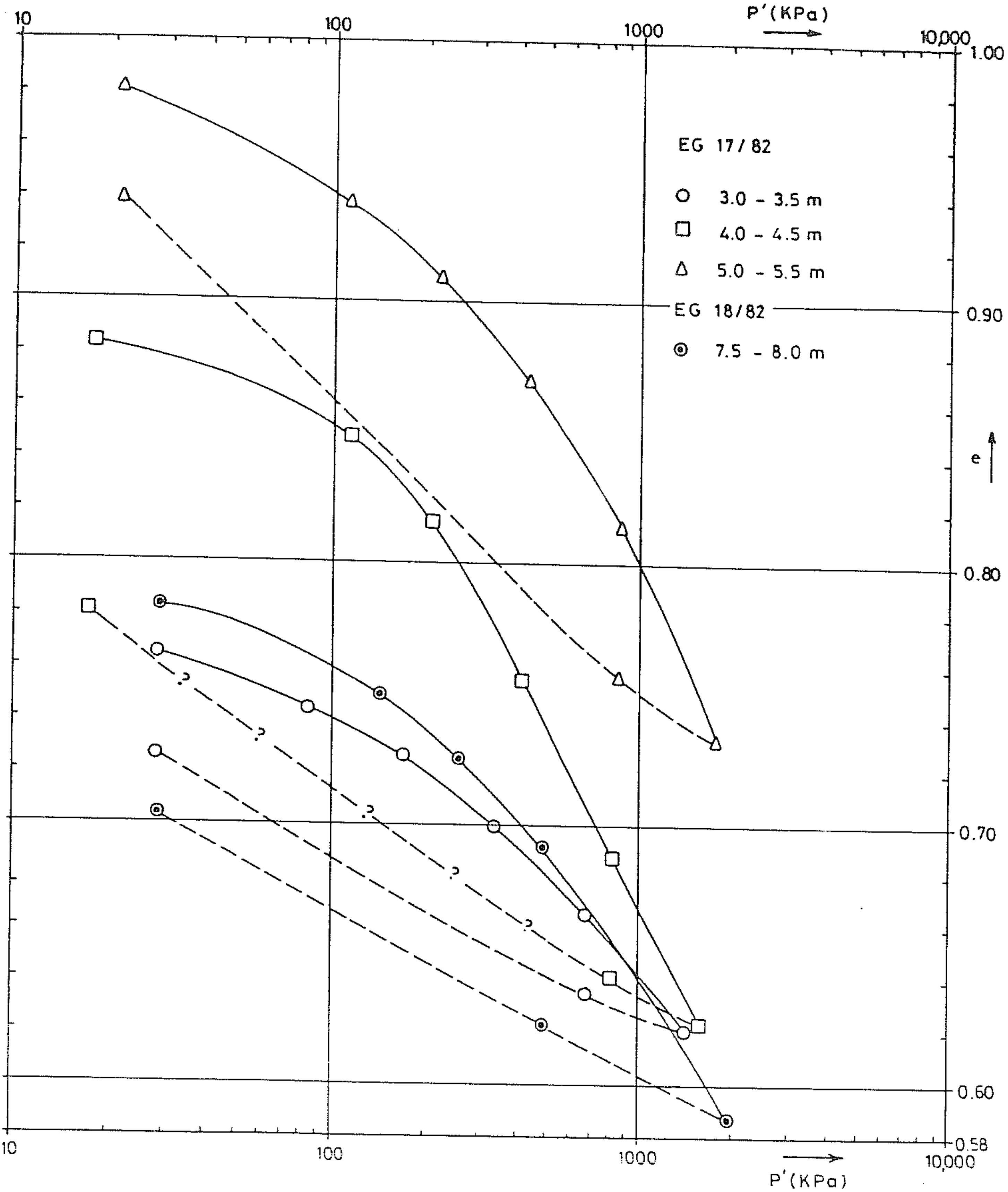
APP. 2.3



OEDOMETER TEST CURVES (e – log P')

VOIDS RATIO v LOG PRESSURE

APP. 2.3

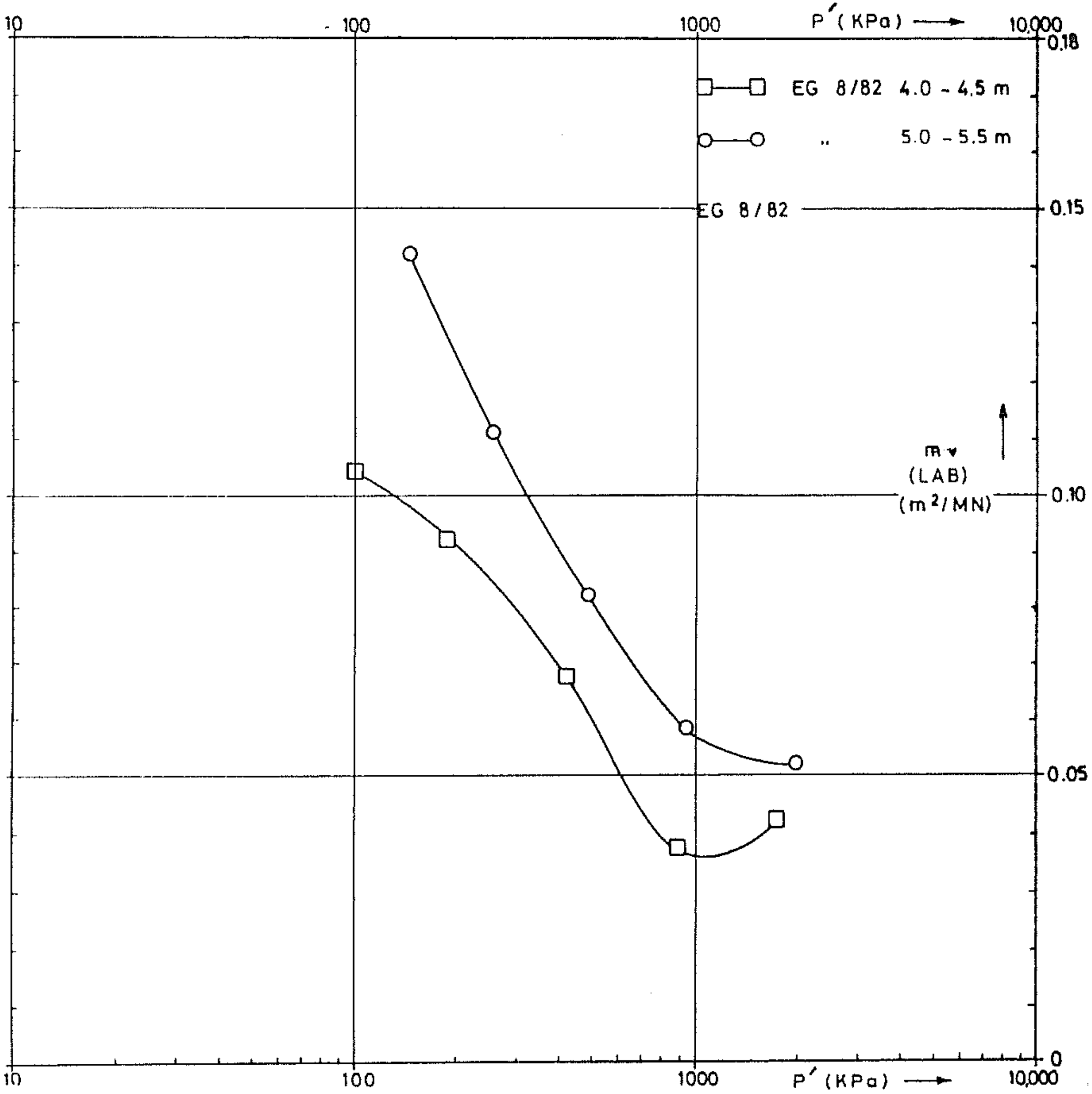


OEDOMETER TEST CURVES (e-log P')

VOIDS RATIO v LOG PRESSURE

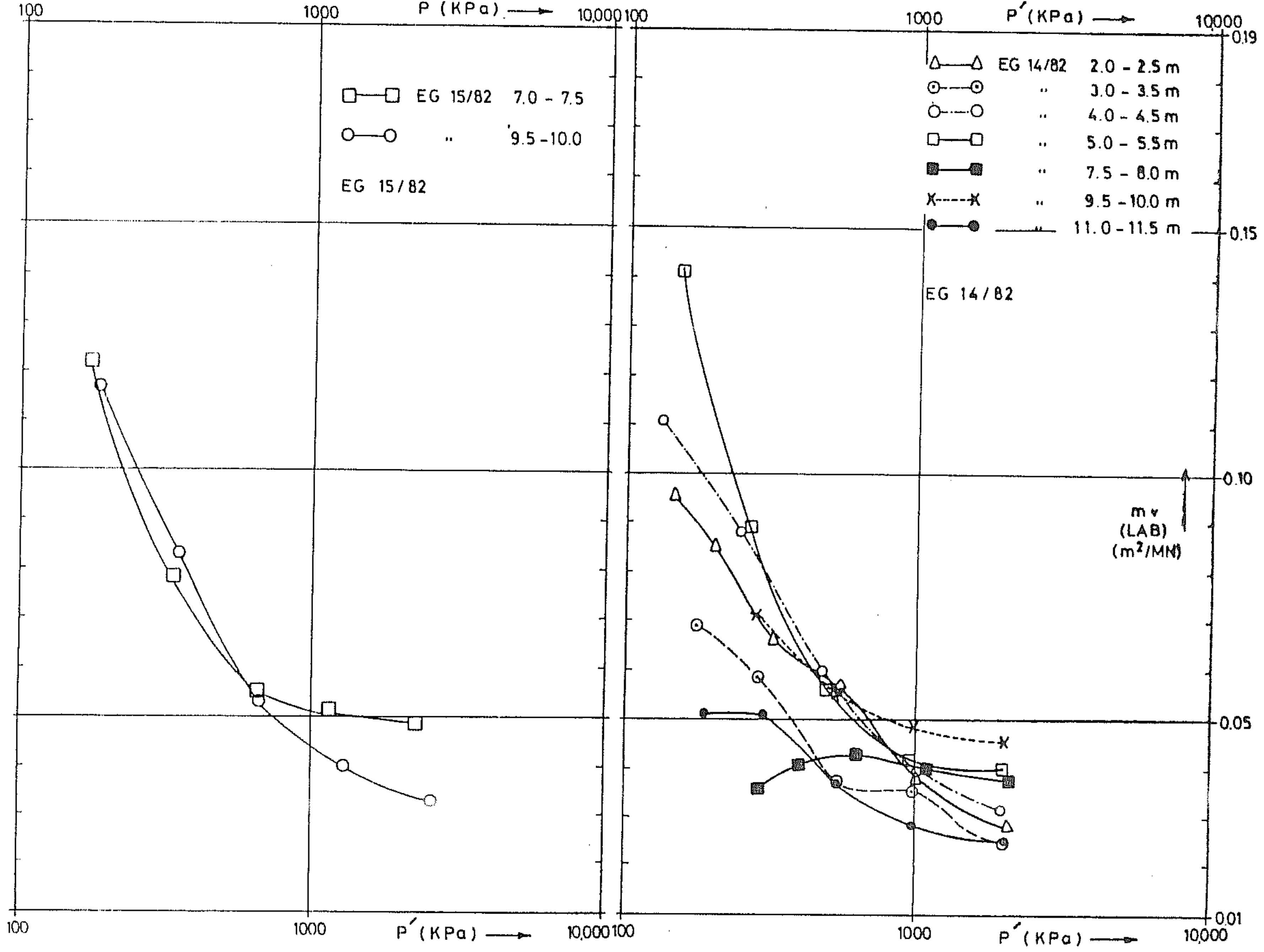
APP, 2.3

OEDOMETER TEST (Modulus of Volume Compression Vs log P)

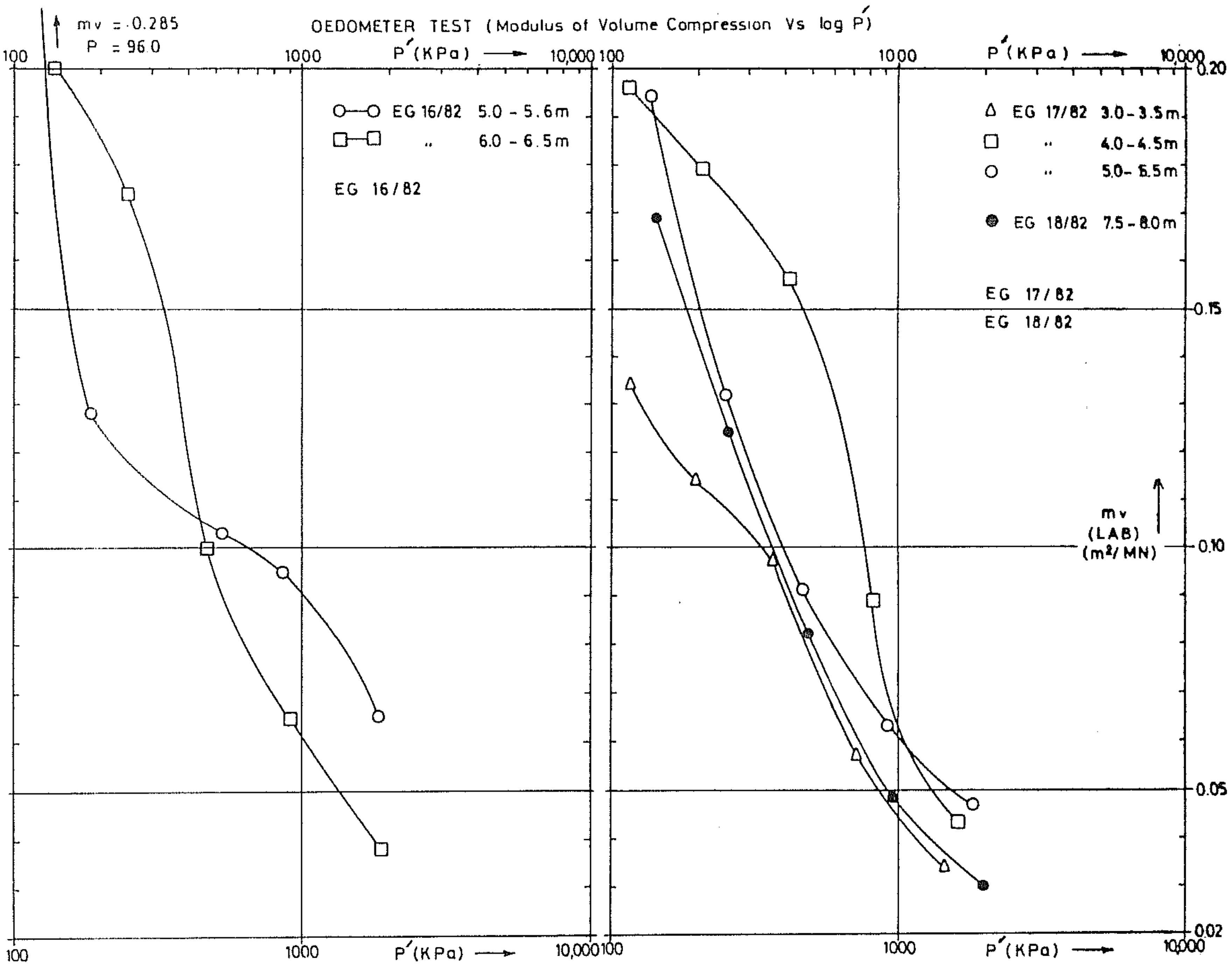


APP. 2.3

OEDOMETER TEST (Modulus of Volume Compression Vs log P′)



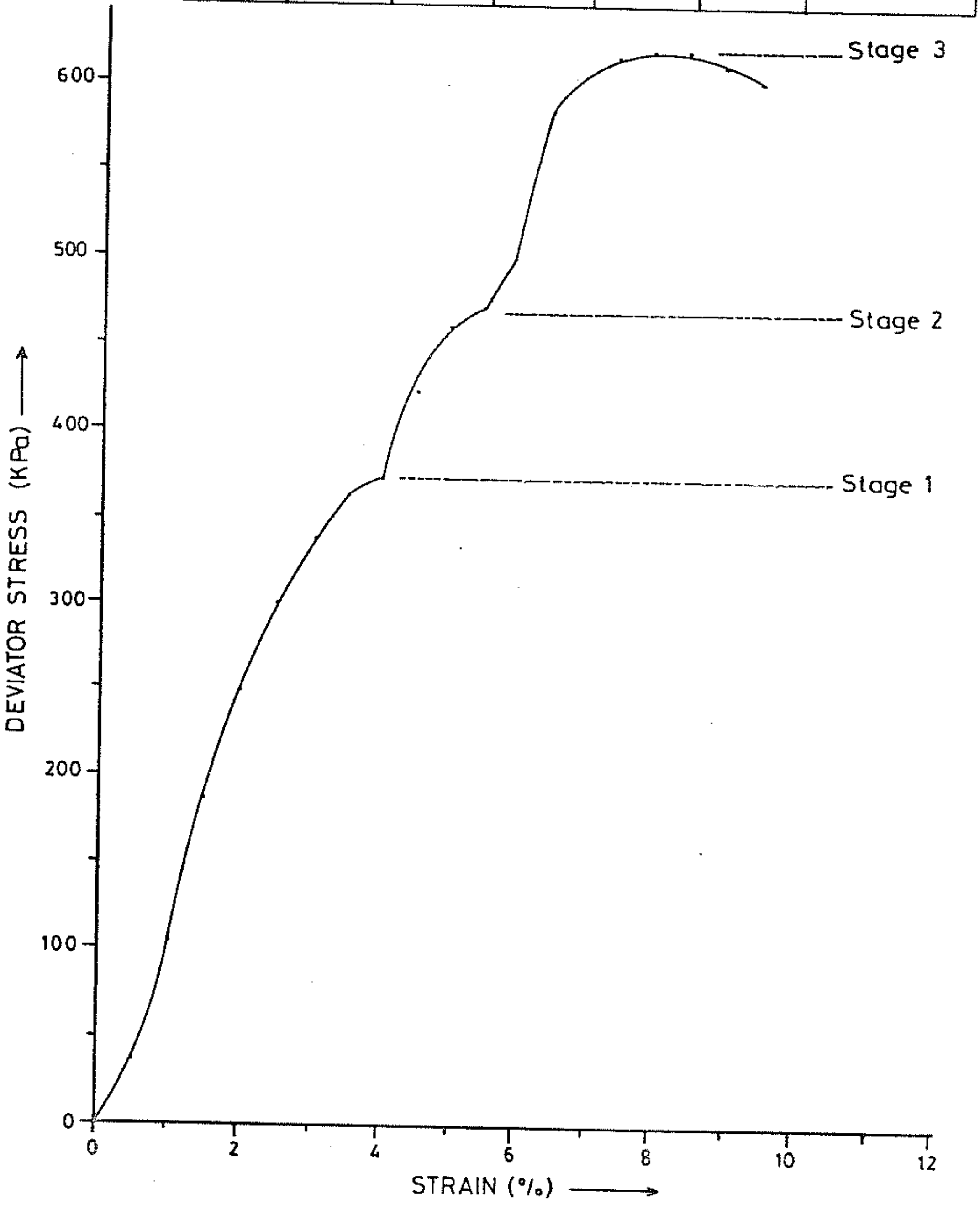
APP. 2.3

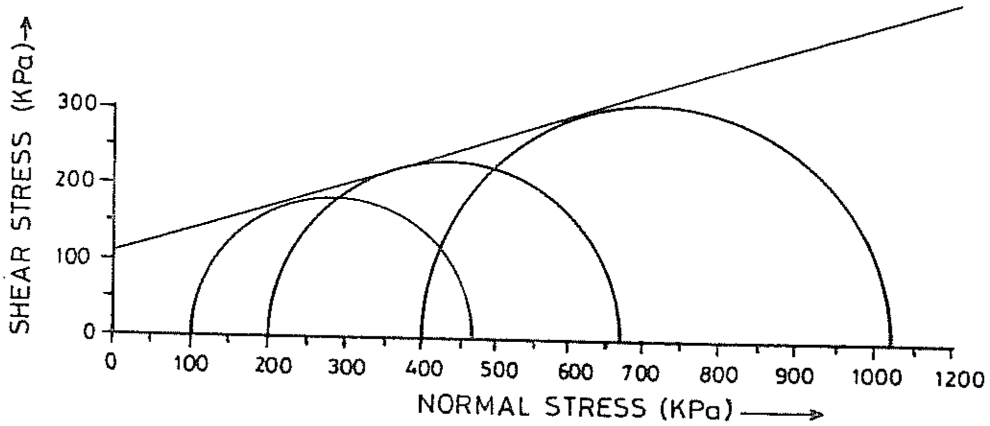

OEDOMETER TEST (Modulus of Volume Compression Vs log P′)

APP. 2.3

MULTISTAGE QU 100mm TRIAXIAL TEST

BH. No	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. %	BULK DENSITY (Mg/m^3)	INITIAL TARGENT MODULUS (Ei) (KPa)
EG 7/82	2.0-2.5	110	17.3	35.000	1.89	16 000



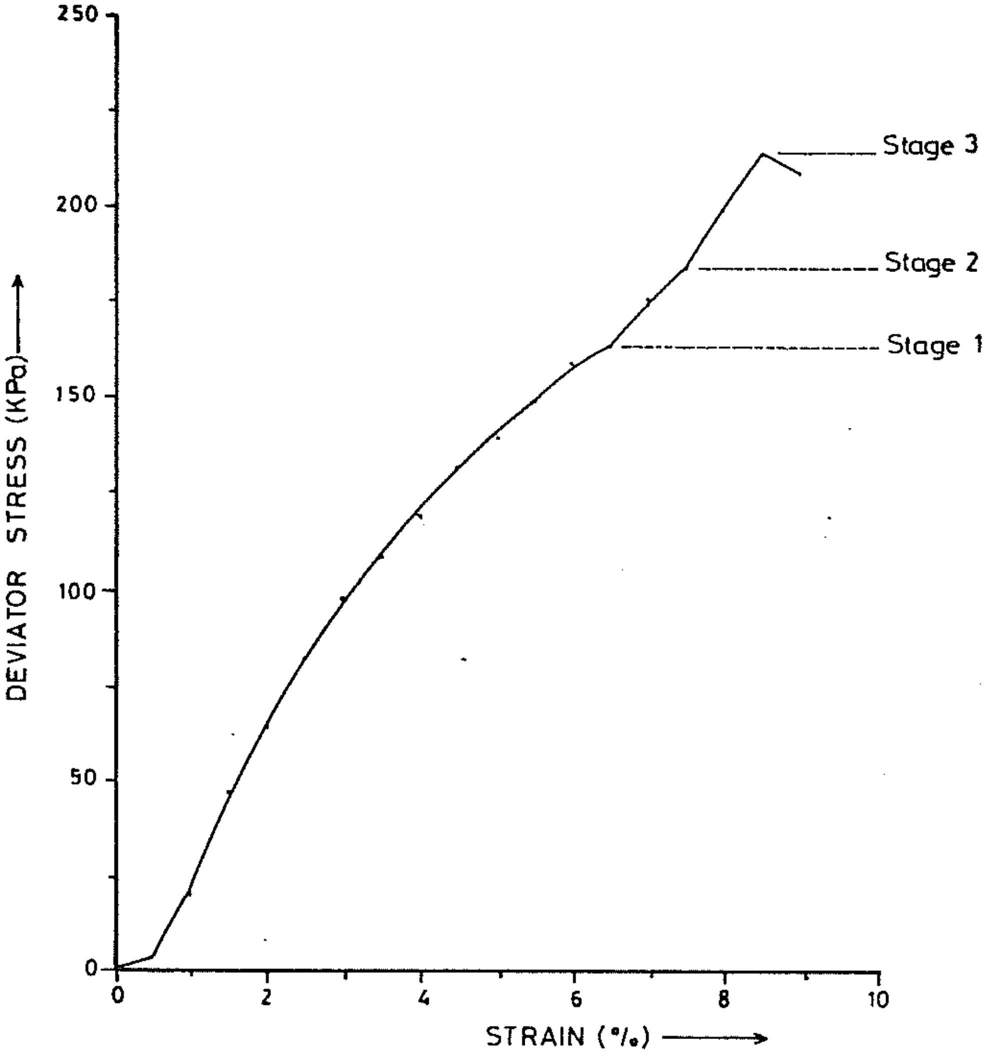


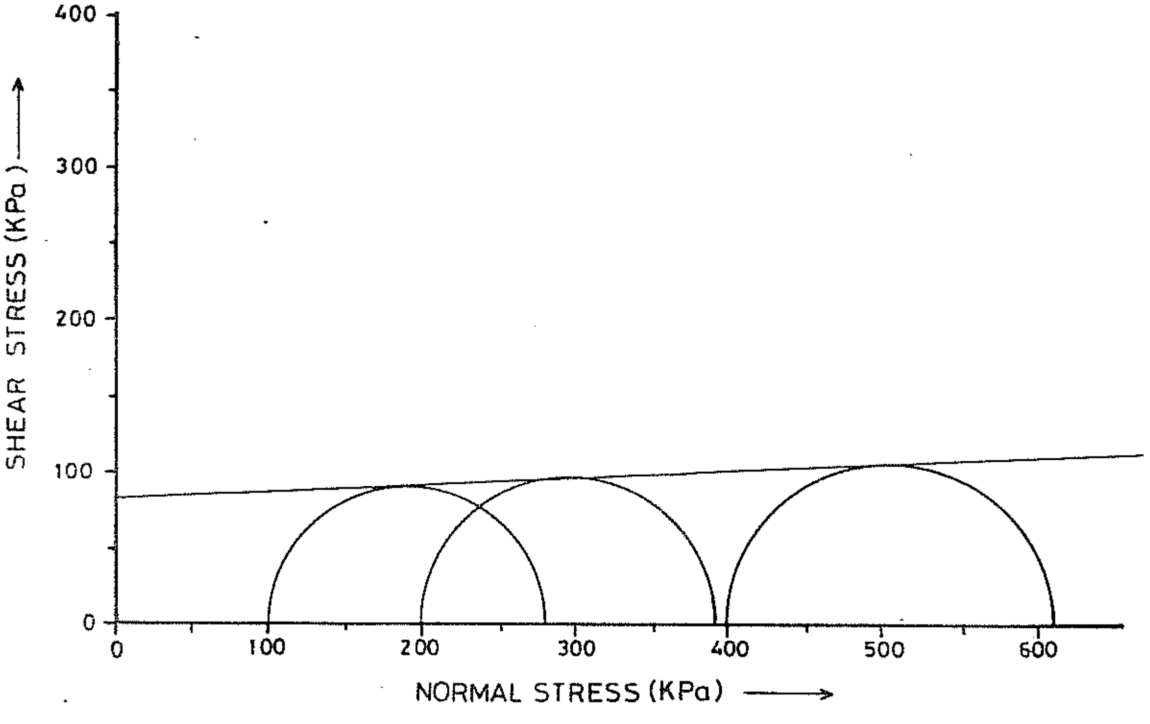
S.D. (E.Geol.) 62/83

APP 24

MULTISTAGE QU 100mm TRIAXIAL TEST

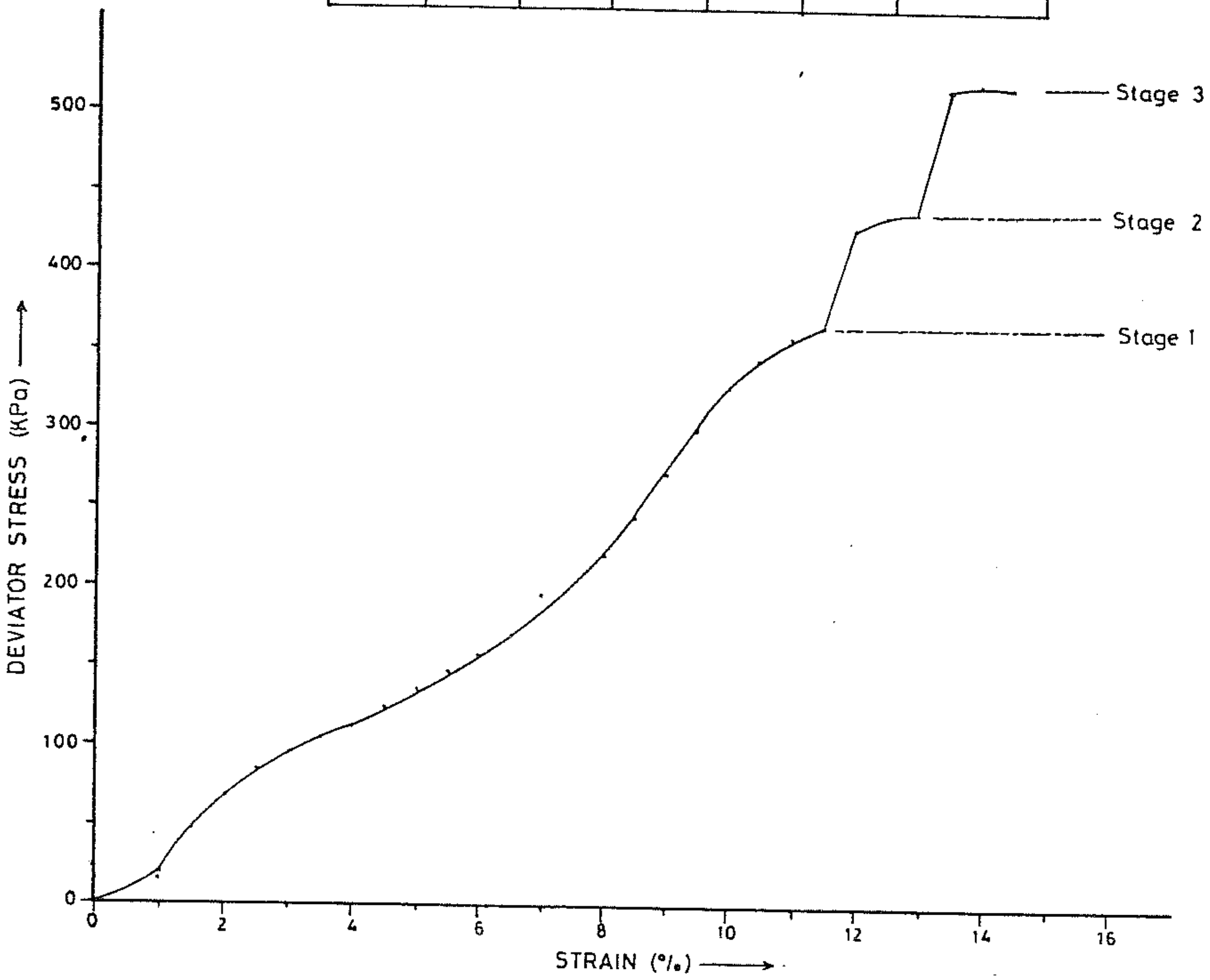
BH. No.	DEPTH (m)	Cu (KPa)	Φu (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG. 7/82	11.0–11.5	82	2.5	31.43	1.83	4 400

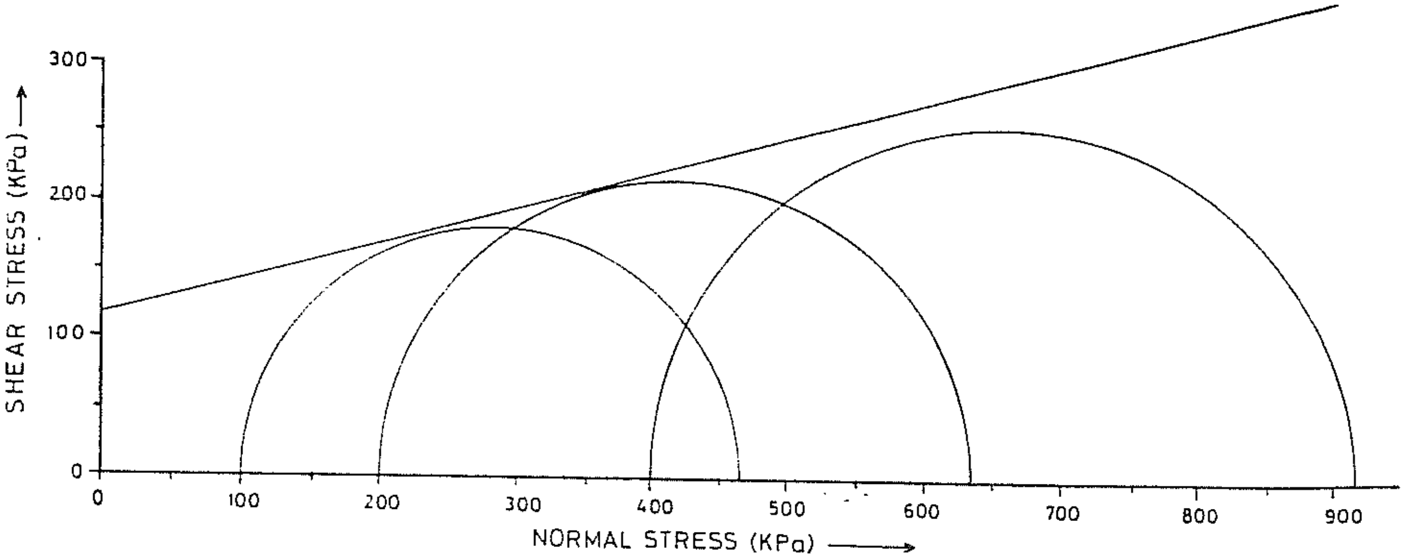




MULTISTAGE QU 100mm TRIAXIAL TEST

BH No	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. %	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG 7/82	13.0-13.5	135	12	31.96	1.892	5 000



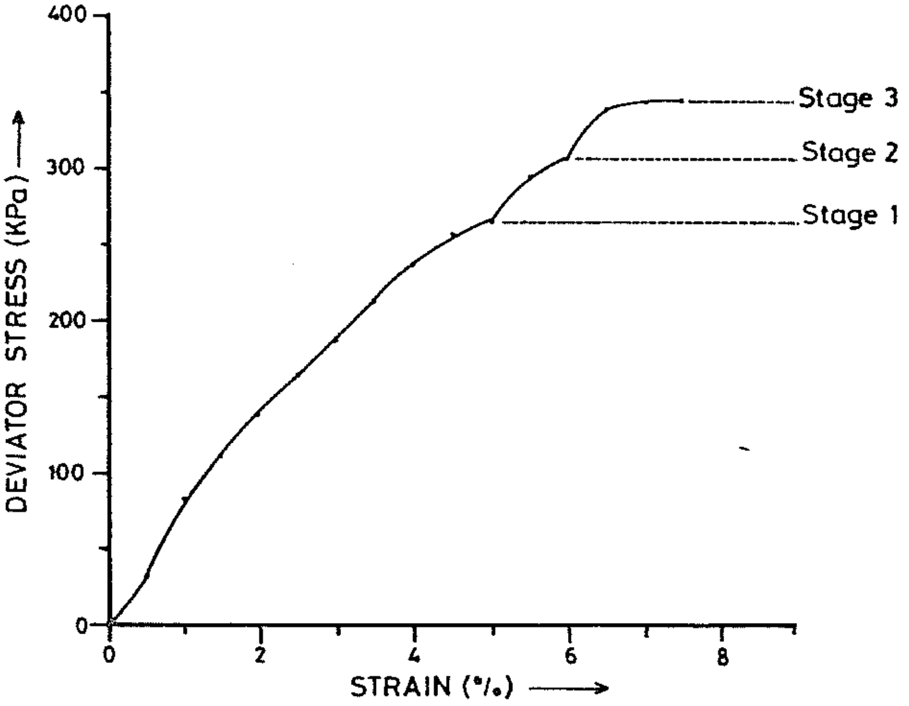


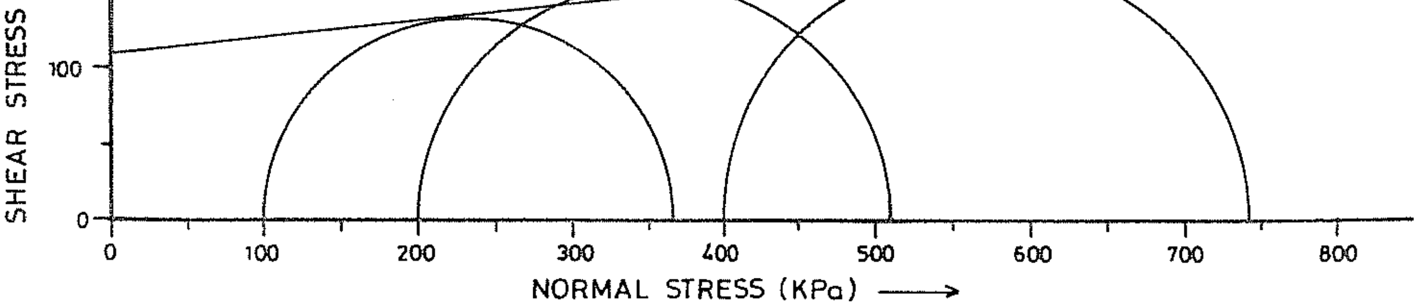
G.S.D. (E.Geol.) 64/83

APP. 2.4

MULTISTAGE QU 100mm TRIAXIAL TEST

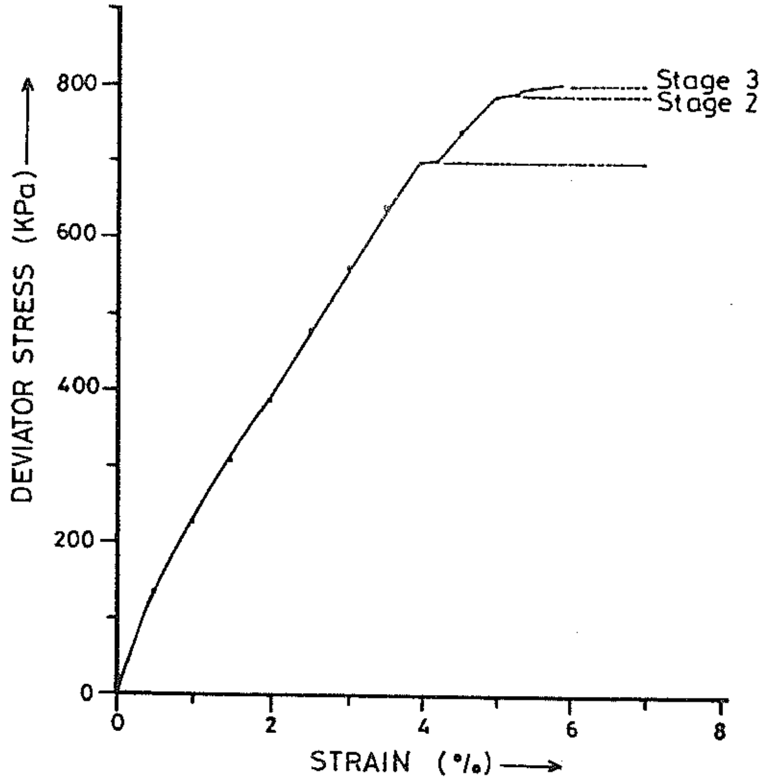
BH. No	DEPTH (m)	Cu (KPa)	ϕu (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG. 8/82	5.0 - 5.5	110	6.2	38.8	1.82	8 500

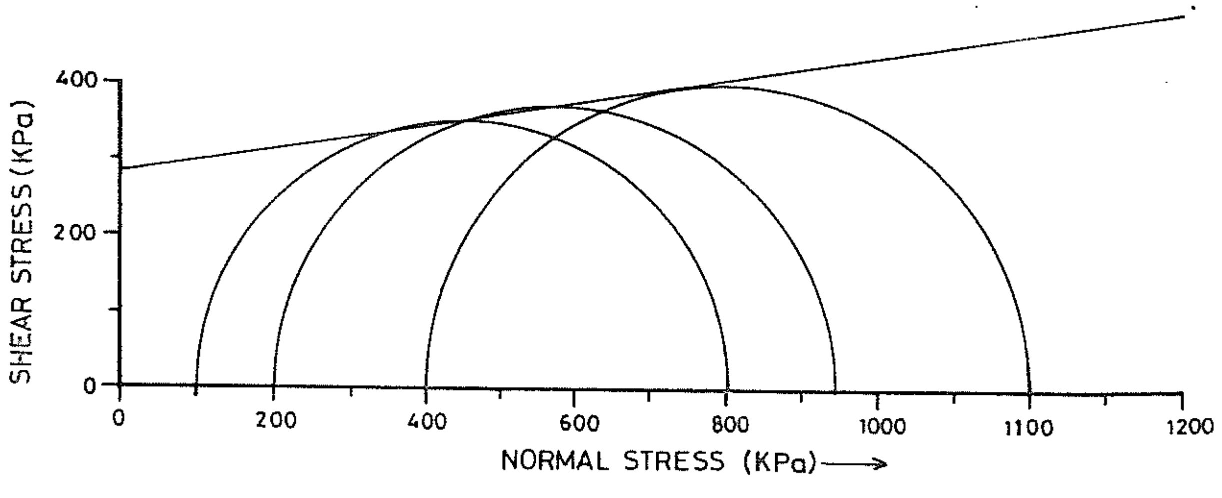




MULTISTAGE QU 100mm TRIAXIAL TEST

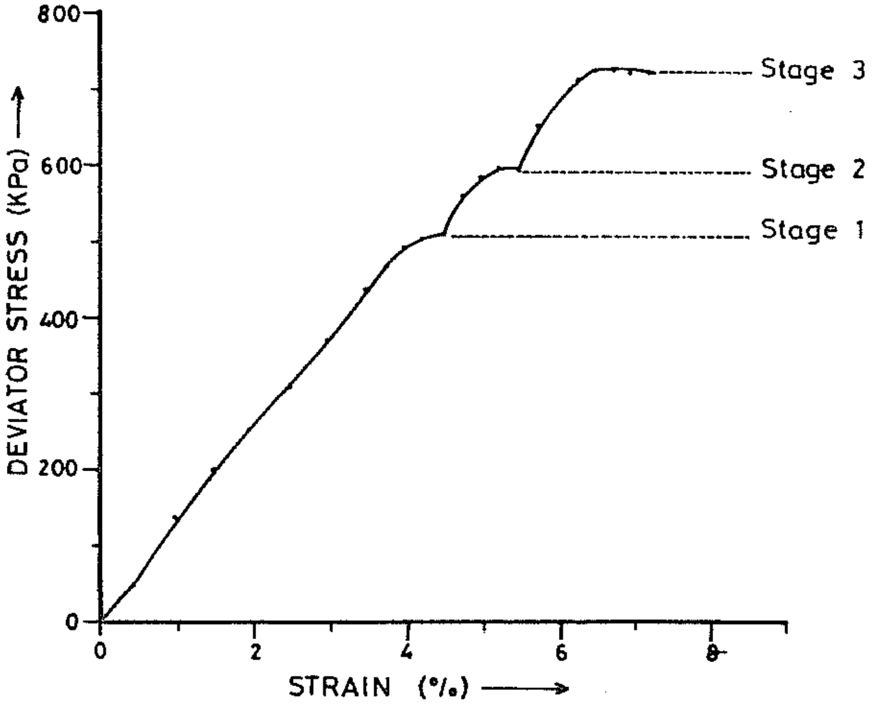
BH. No.	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m³)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG.14/82	3.0–3.5	2.85	8.6	25.9	1.92	22 000

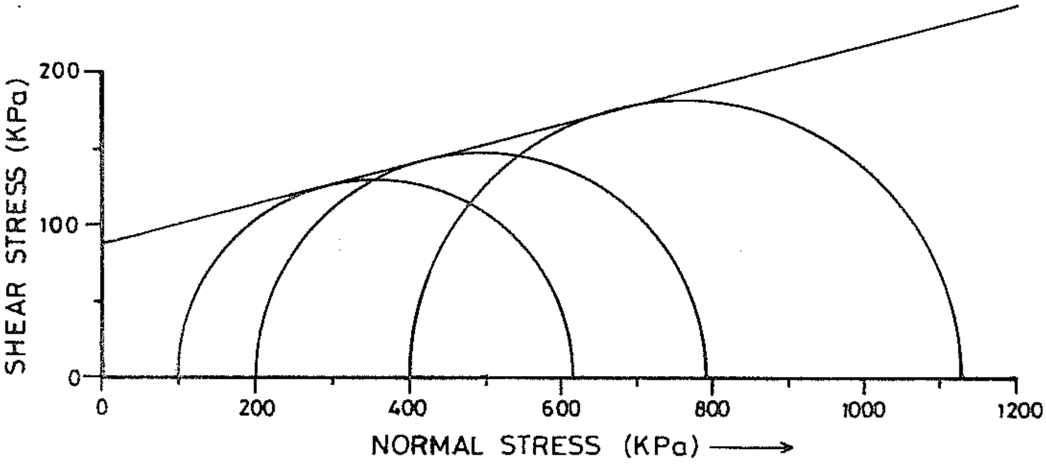




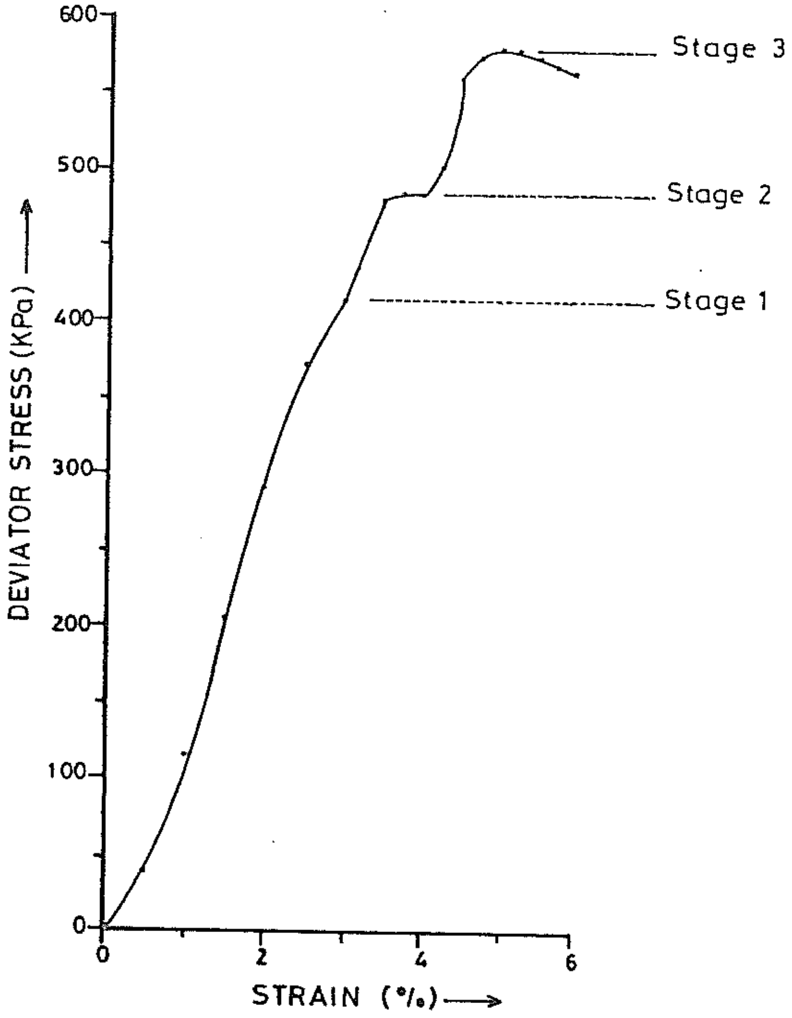
MULTISTAGE QU 100mm TRIAXIAL TEST

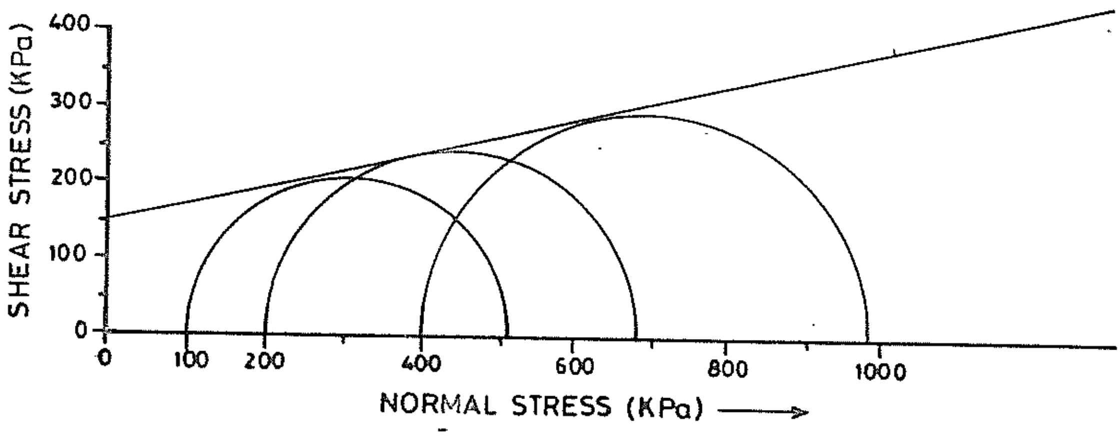
BH. No	DEPTH (m)	Cu (KPa)	Φu (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG. 14/82	4.0–4.5	175	14.8	29.9	1.92	14 500





BH. No	DEPTH (m)	Cu (KPa)	φ_u (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG.14/82	6.0 – 6.5	150	13.4	29.2	1.78	17 500

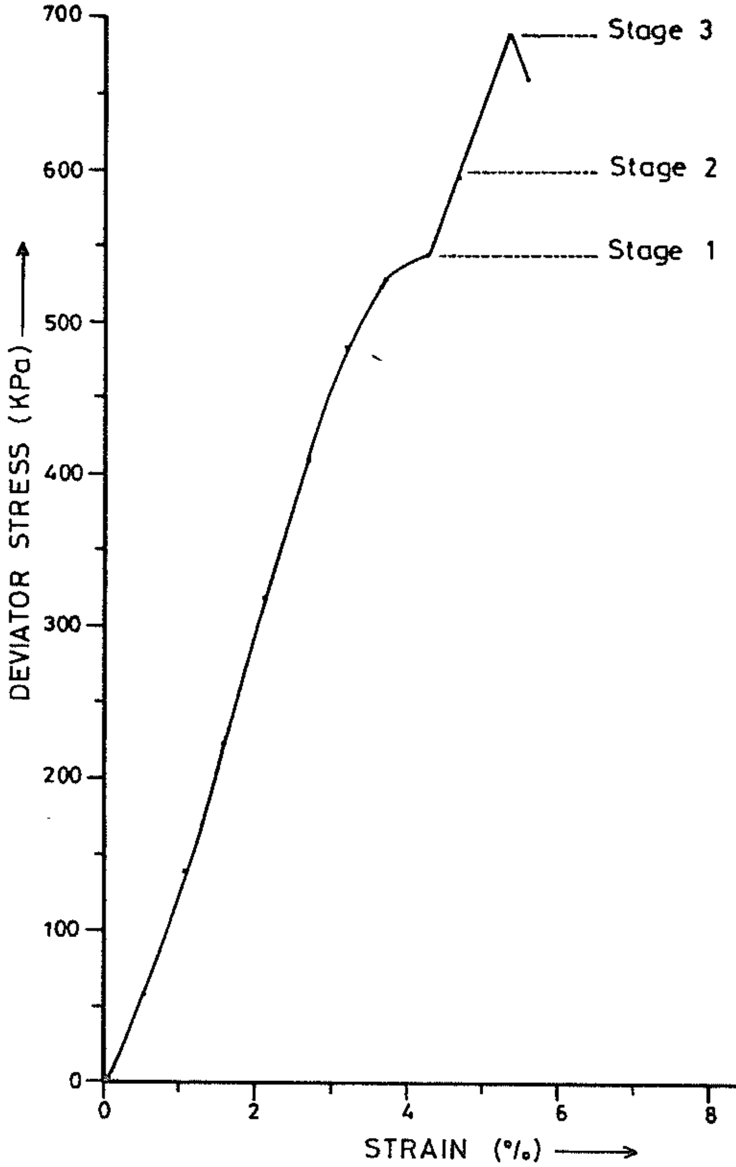


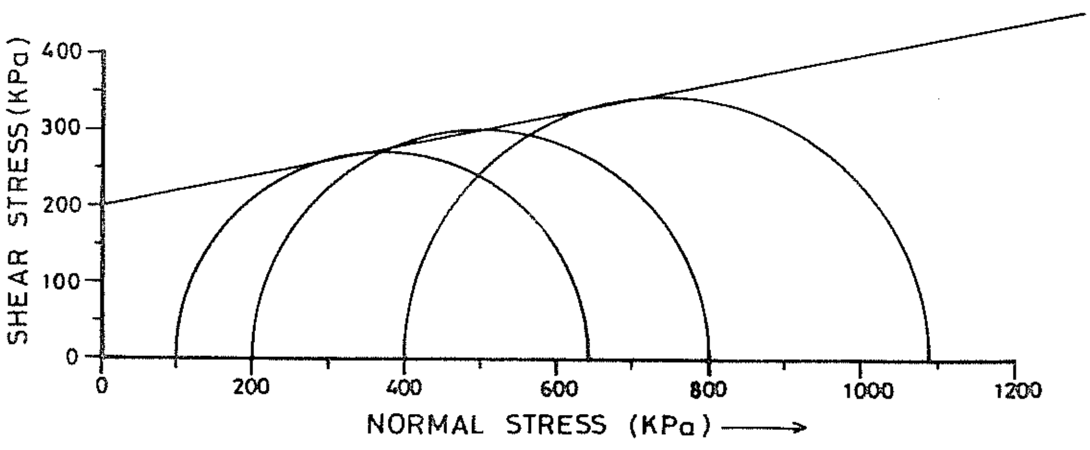


G.S.D. (E.Geol) 68/83

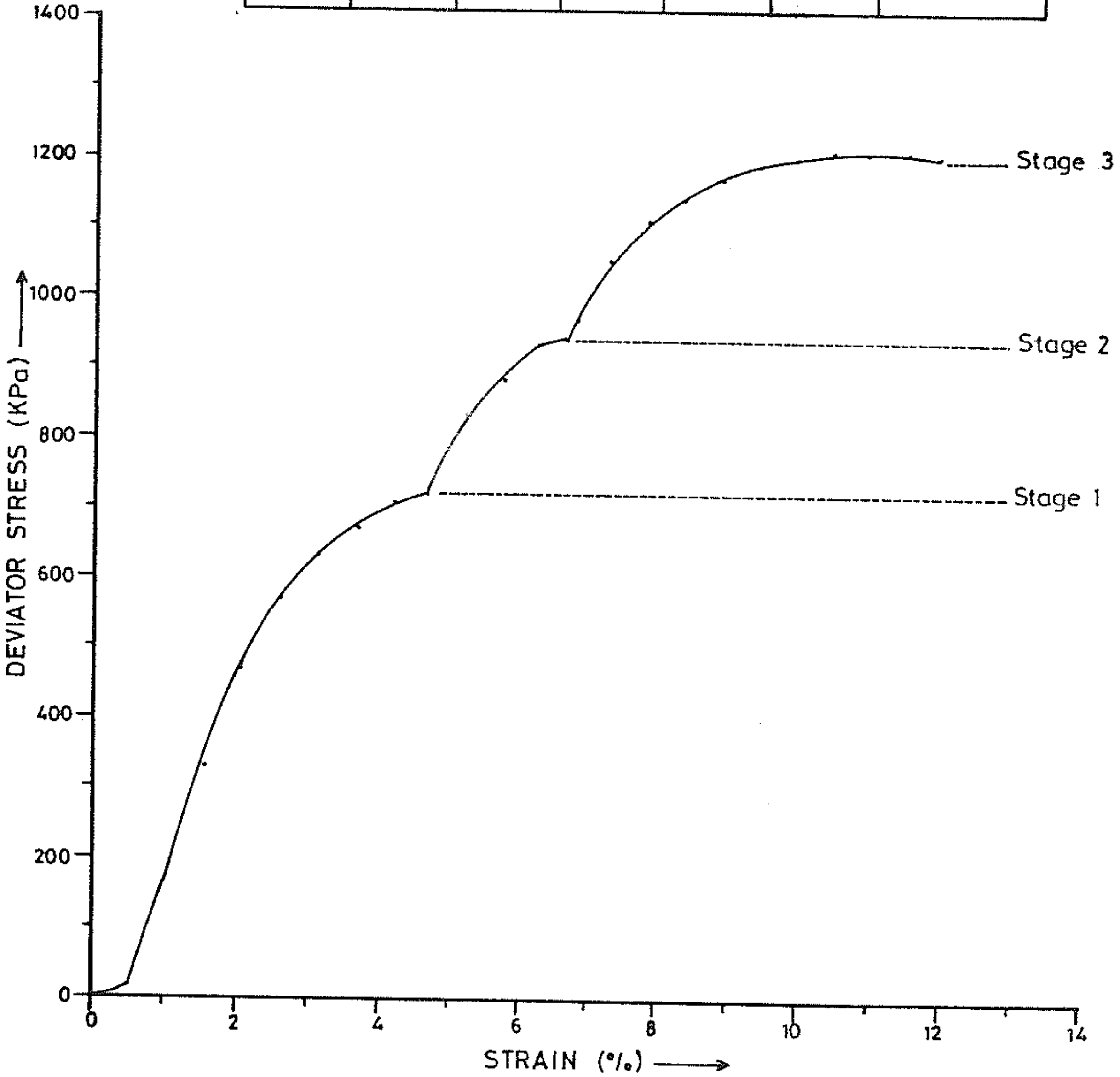
APP. 2.4

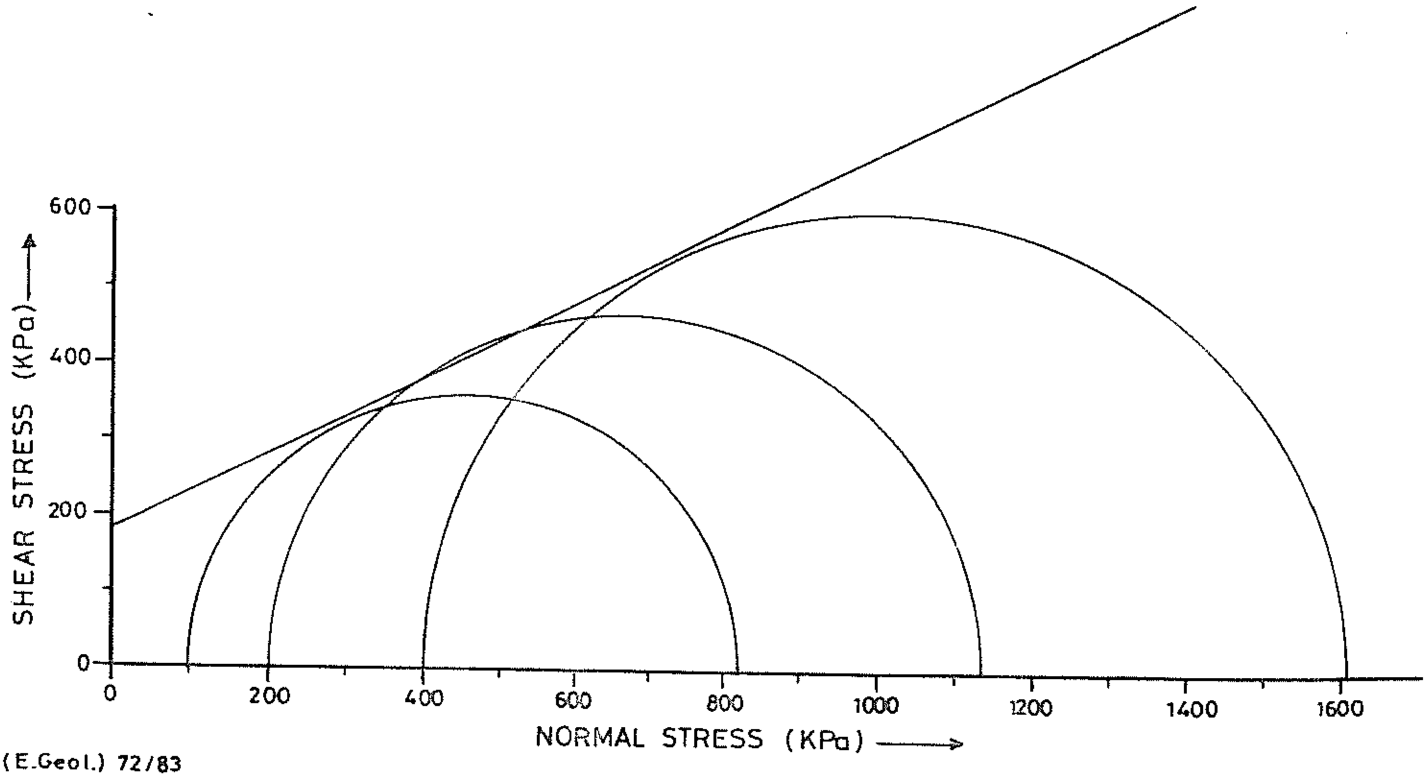
BH. No	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m³)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG. 15/82	9.5–10.0	200	10.6	27.5	1.85	15000





BH. No	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m³)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG 16/84	4.0 – 4.5	18.0	26	16.7	1.71	30000

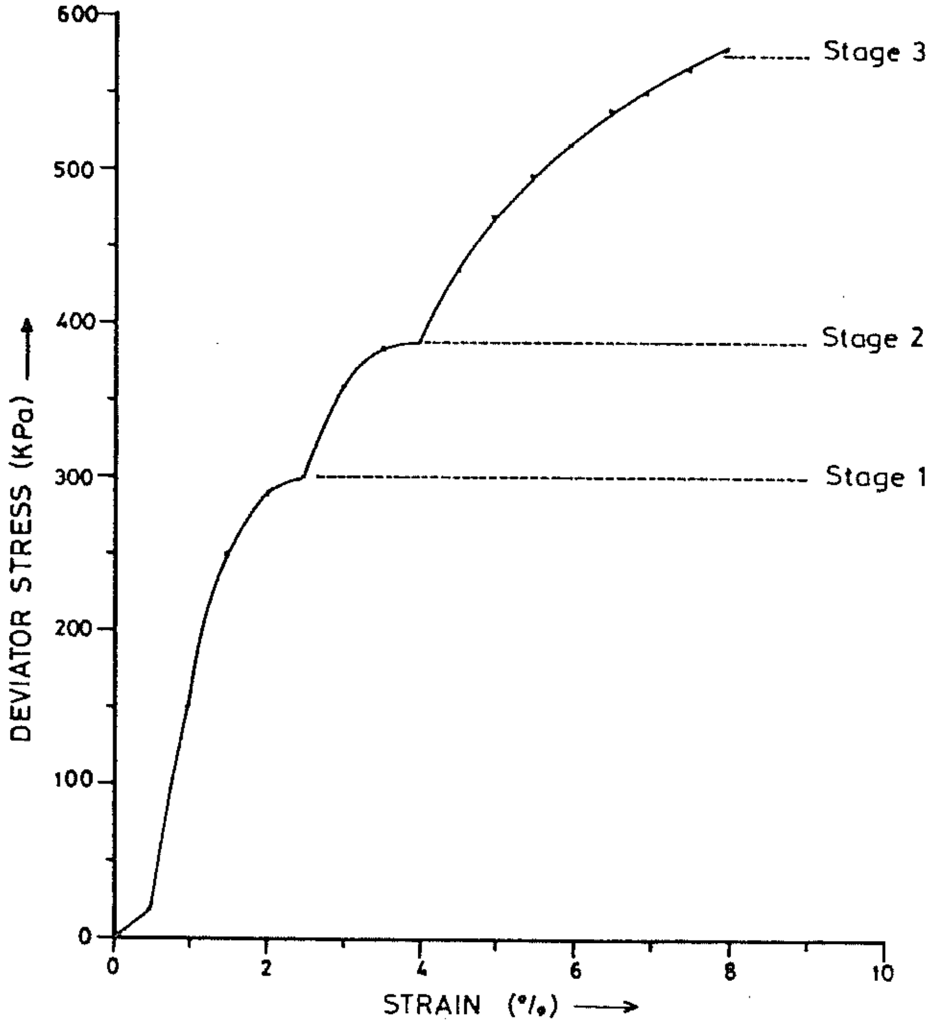


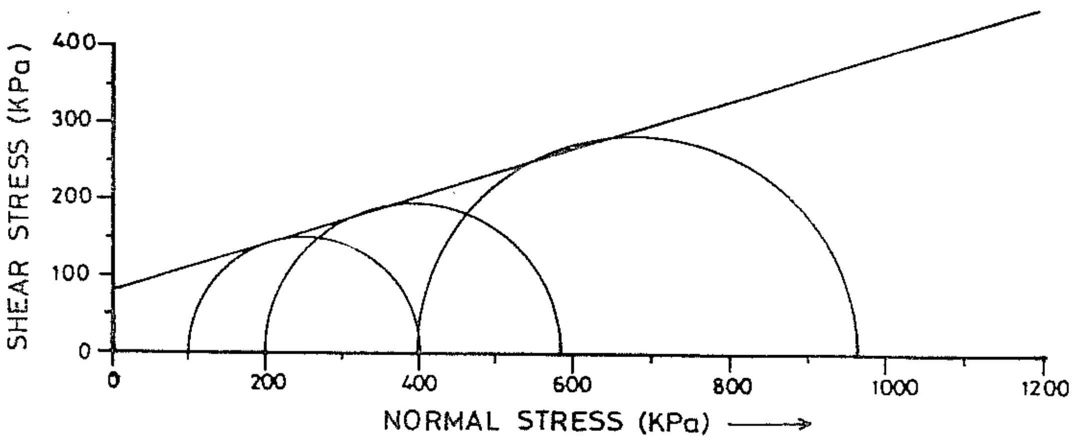


D. (E.Geol.) 72/83

MULTISTAGE QU 100mm TRIAXIAL TEST

BH. No	DEPTH (m)	Cu (KPa)	ϕ_u (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG. 16/82	5.0 -5.5	80	16.7	18.7	1.59	25 000

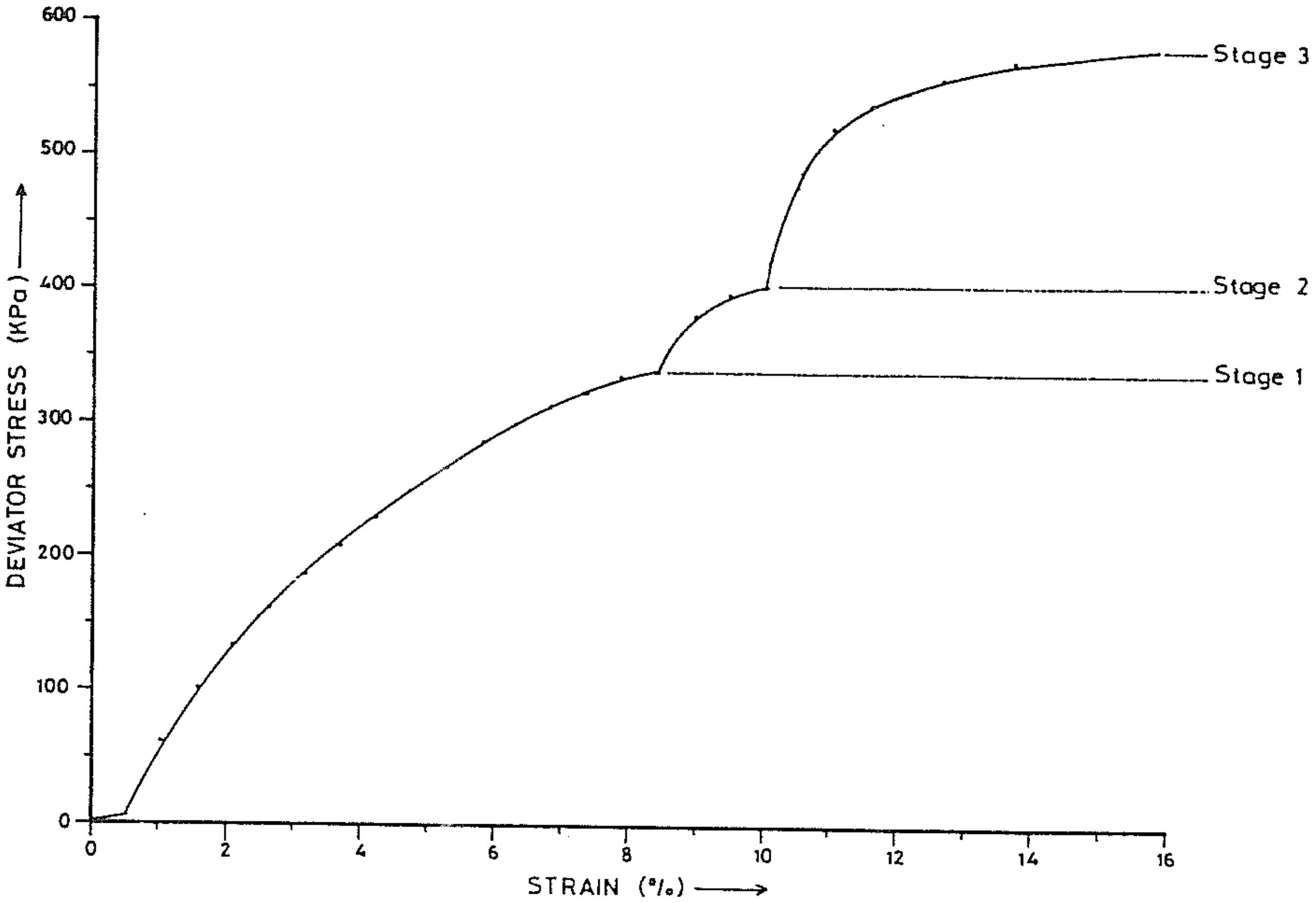


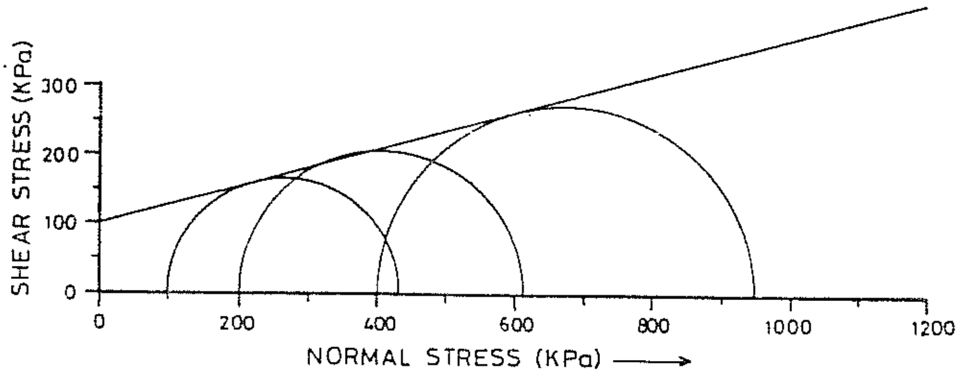


APP. 2.4

MULTISTAGE QU 100mm TRIAXIAL TEST

BH. No.	DEPTH (m)	Cu (KPa)	ϕ_u (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG.16/82	6.0-6.5	100	15.33	22.45	1.87	7 500



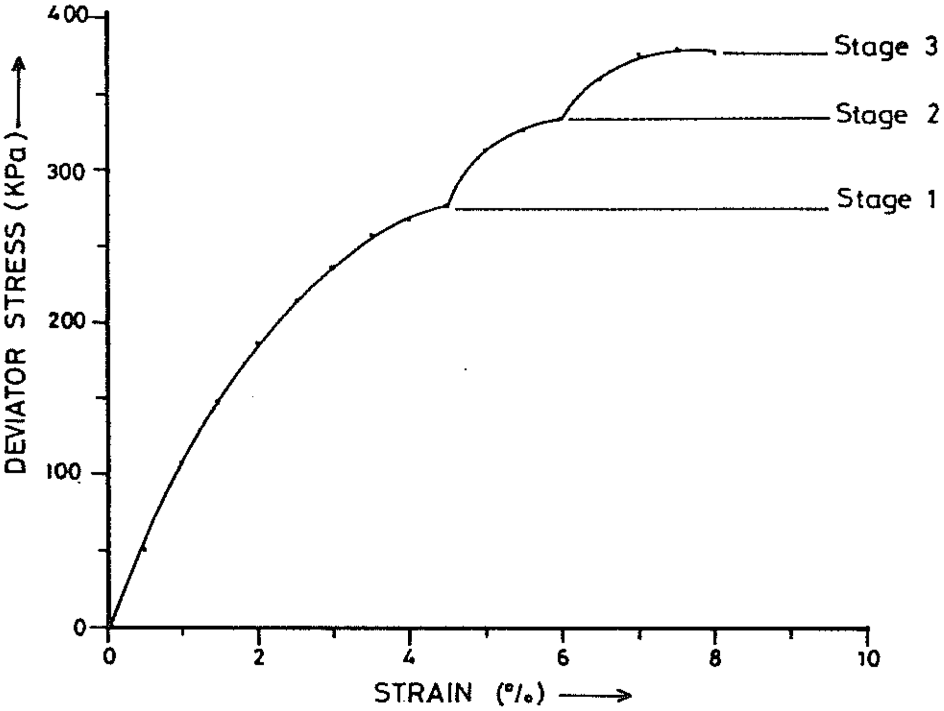


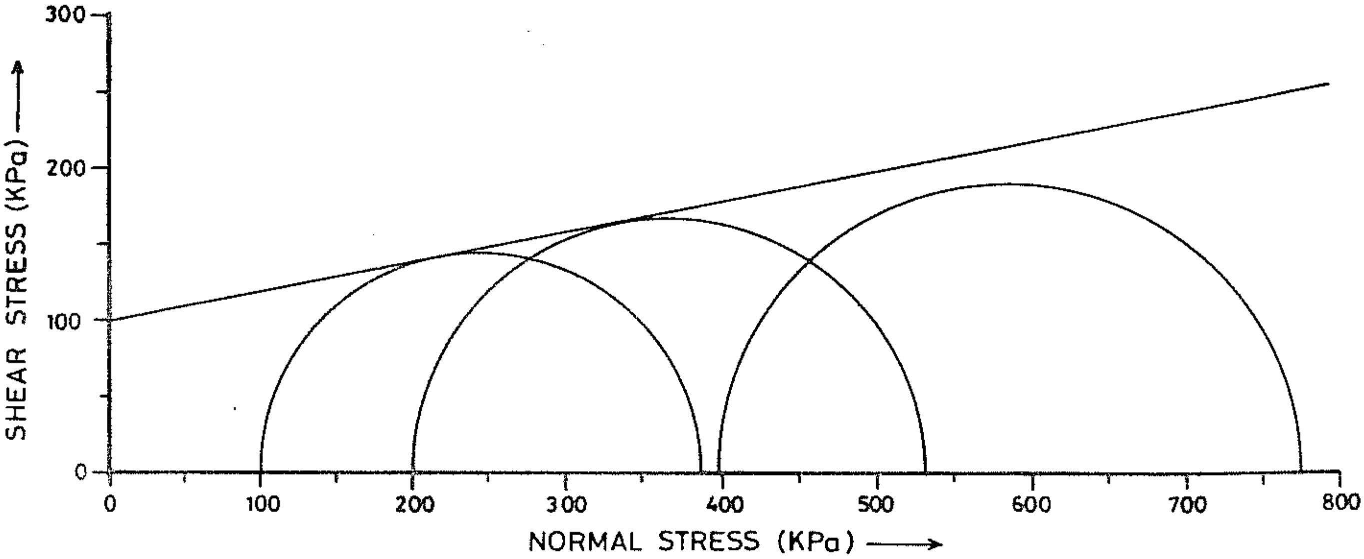
G.S.D. (E.Geol.) 74/83

APP. 2.4

MULTISTAGE QU 100mm TRIAXIAL TEST

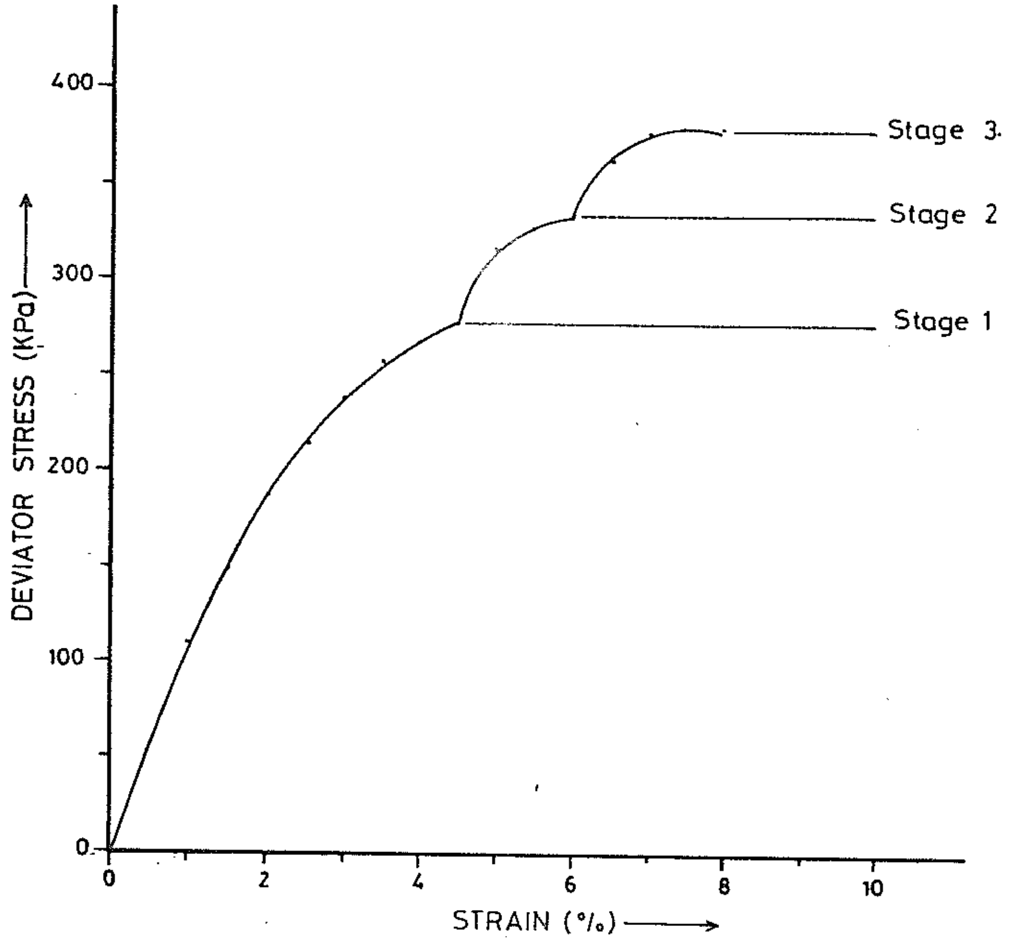
BH. No.	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m³)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG 17/12	3.0–3.5	100	10.9	25.6	1.94	10 000

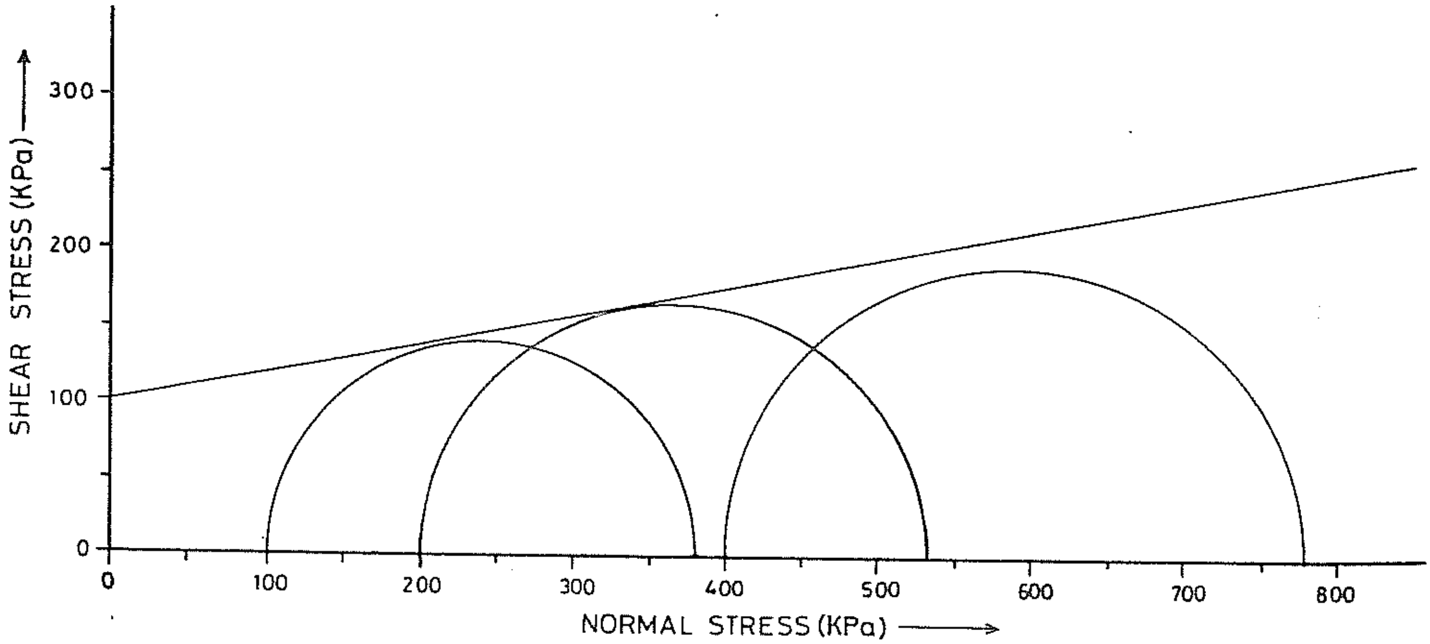




MULTISTAGE QU 100mm TRIAXIAL TEST

BH. No.	DEPTH (m)	Cu (KPa)	φ_u (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (EI) (KPa)
EG. 17/ 82	3.0-3.5	100	10.9	25.6	1.94	11 200

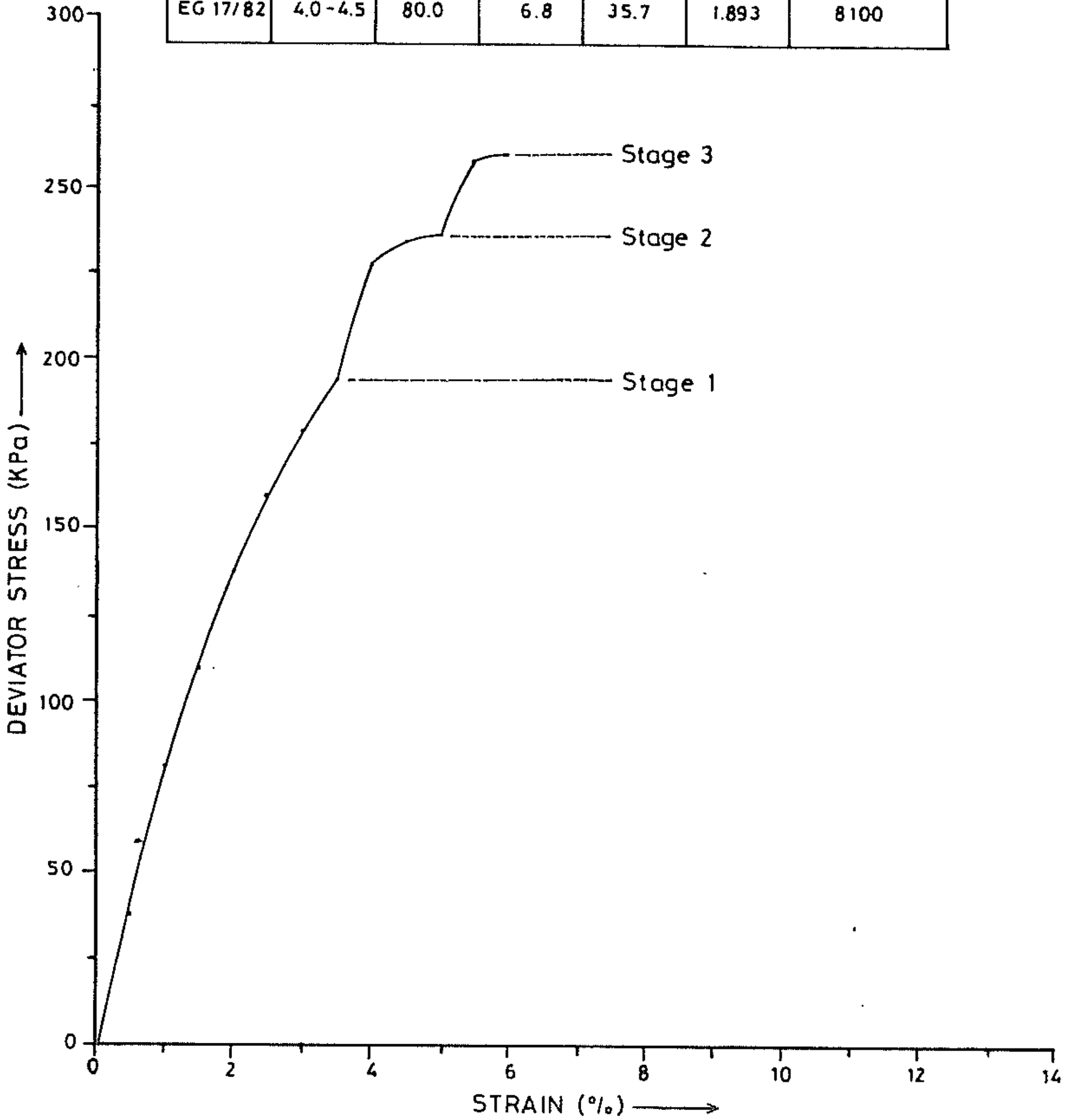


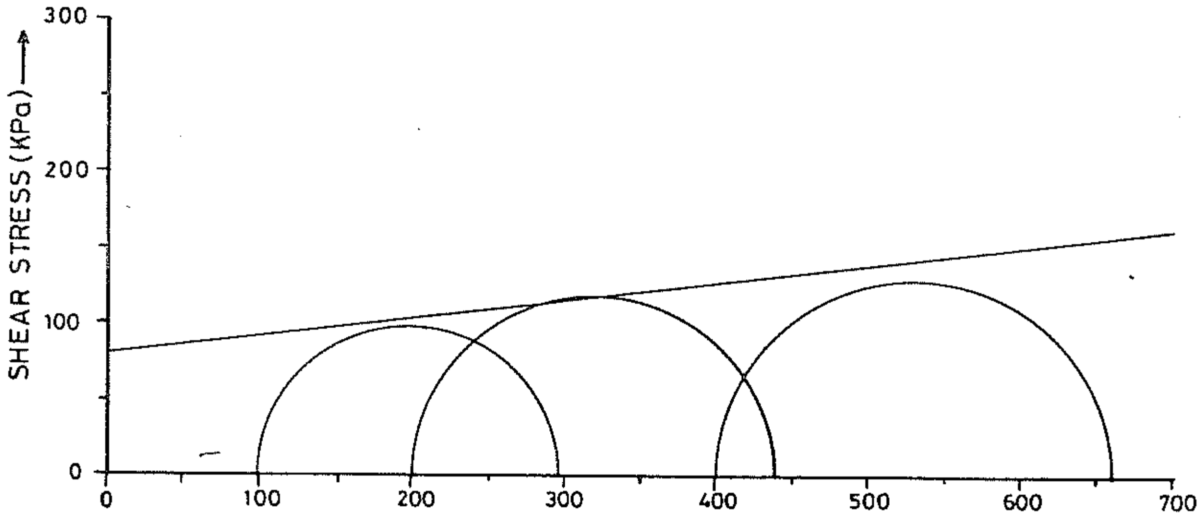


APP. 2.4

MULTISTAGE QU 100mm TRIAXIAL TEST

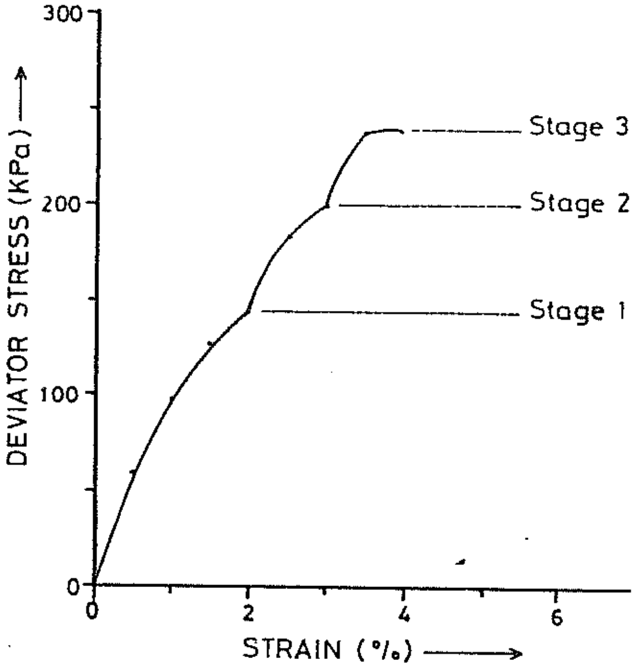
BH No.	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. %	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (Ei) (KPa)
EG 17/82	4.0 - 4.5	80.0	6.8	35.7	1.893	8100

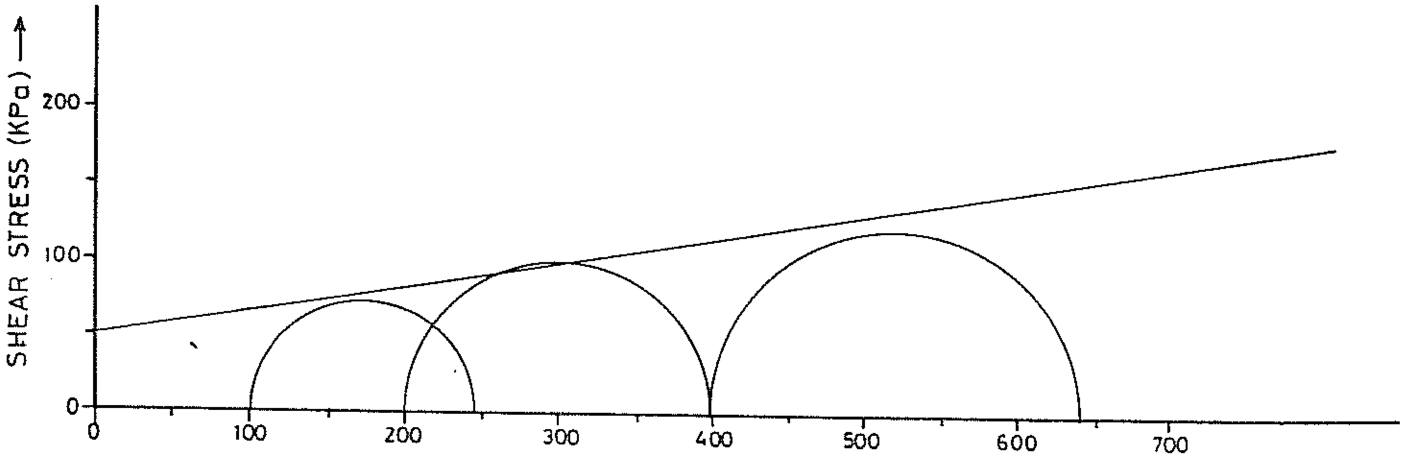




MULTISTAGE QU 100mm TRIAXIAL TEST

BH. No	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m³)	INITIAL TANGENT MODULUS (EI) (KPa)
EG.17/82	5.0~5.5	50	8.7	32.8	1.87	10.000

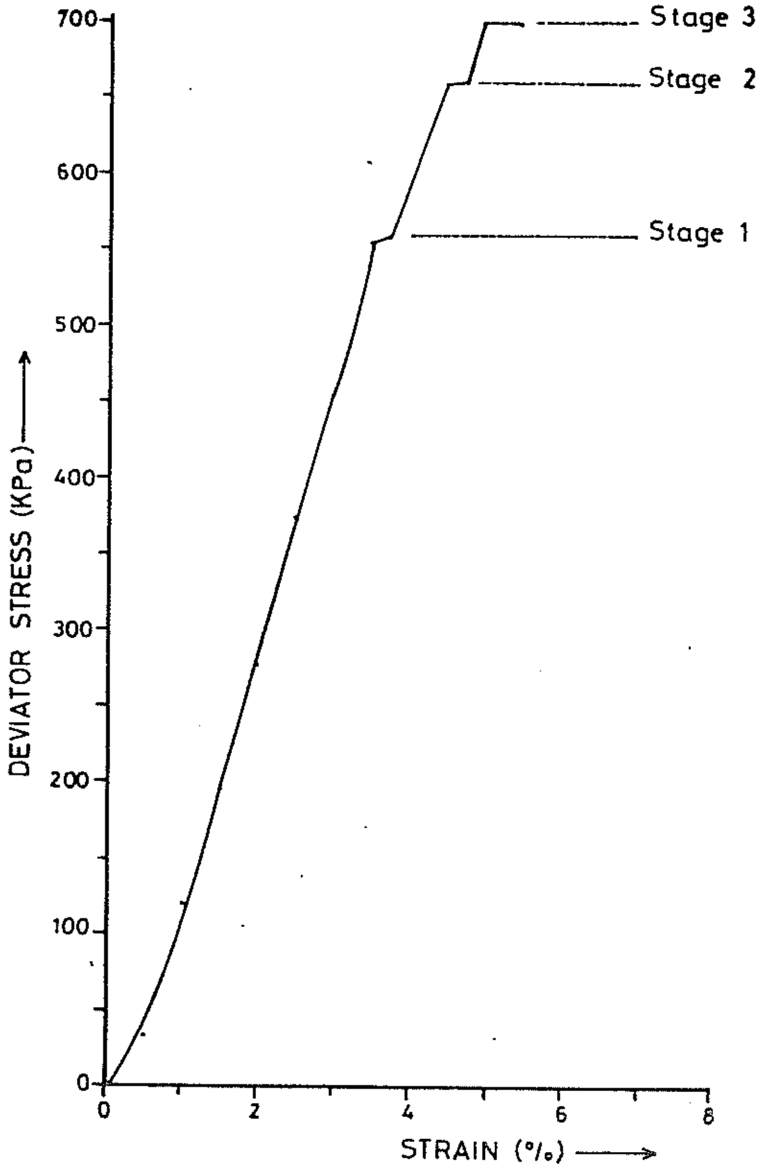


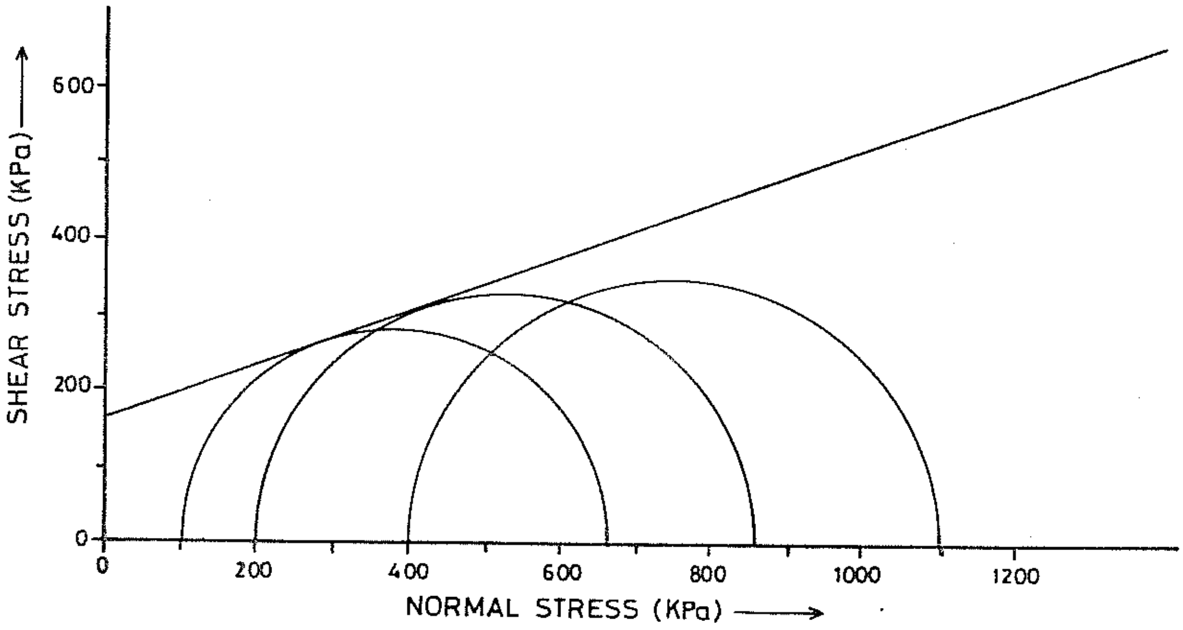


APP. 2.4

MULTISTAGE QU 100mm TRIAXIAL TEST

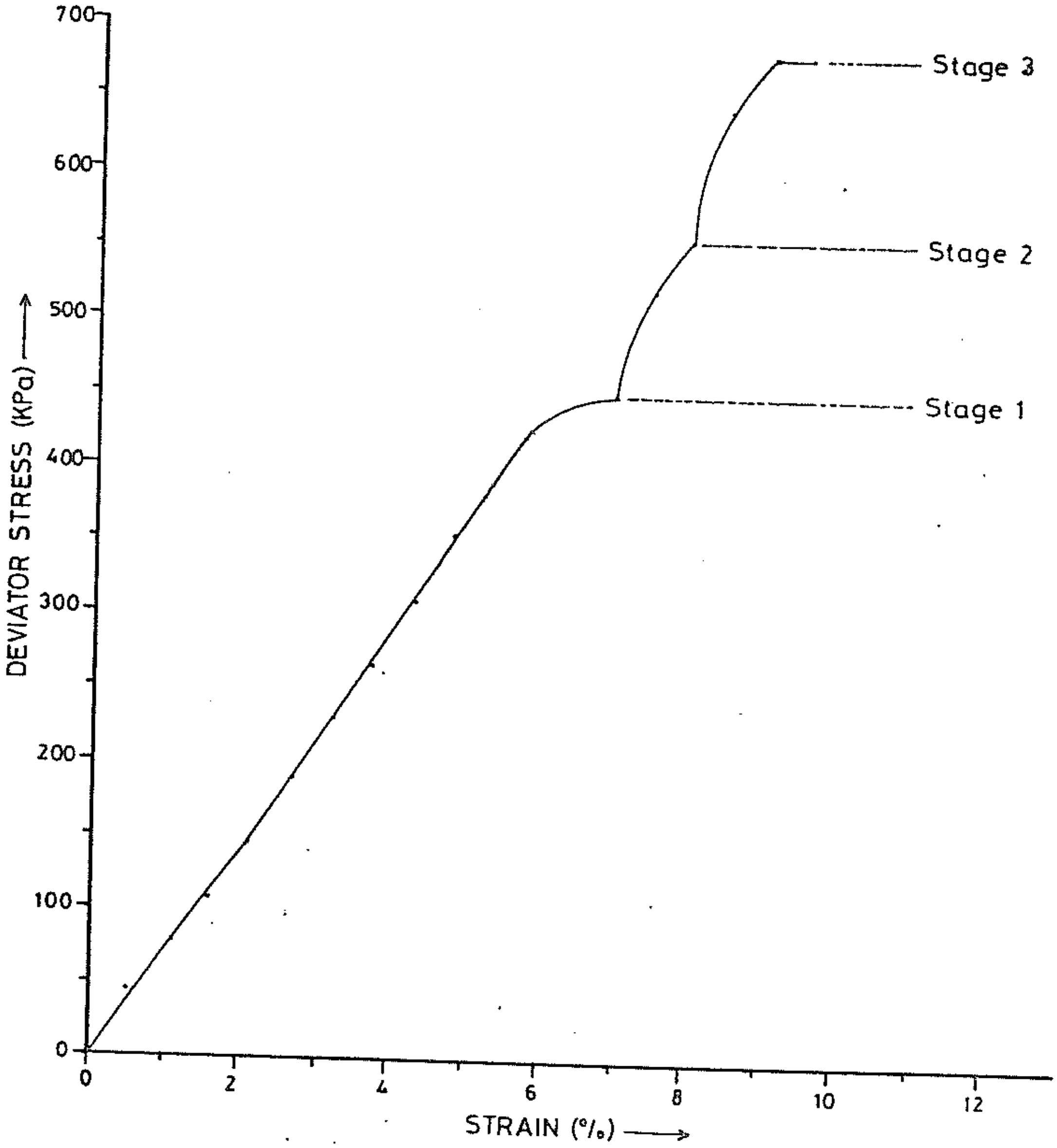
BH. No.	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. (%)	BULK DENSITY (Mg/m3)	INITIAL TANGENT MODULUS (EI) (KPa)
EG. 17/82	6.0-6.5	165	19	27.7	1.95	17 500

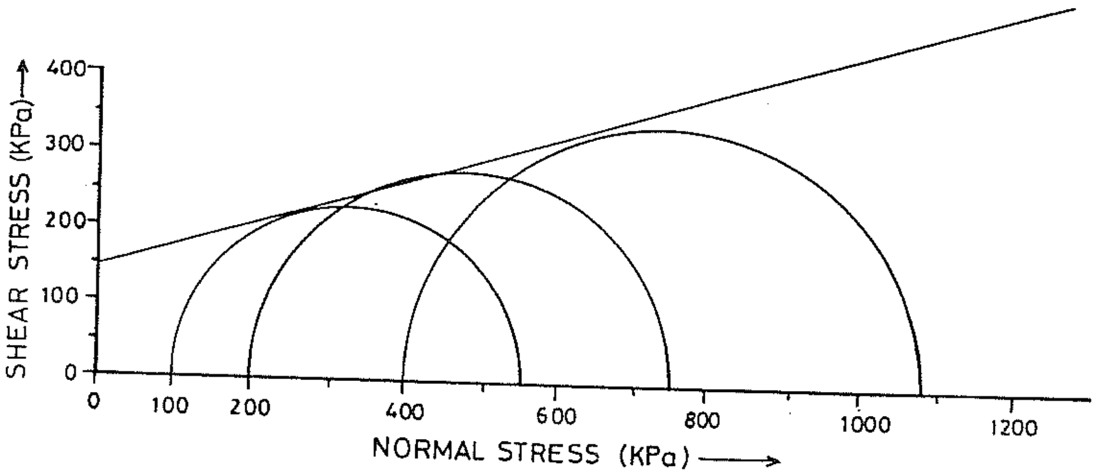




MULTISTAGE QU 100mm TRIAXIAL TEST

BH. No.	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. %	BULK DENSITY (Mg/m^3)	INITIAL TANGENT MODULUS (EI) (KPa)
EG. 18/82	9.5 - 10.0	145	16	31.86	1.87	6 500



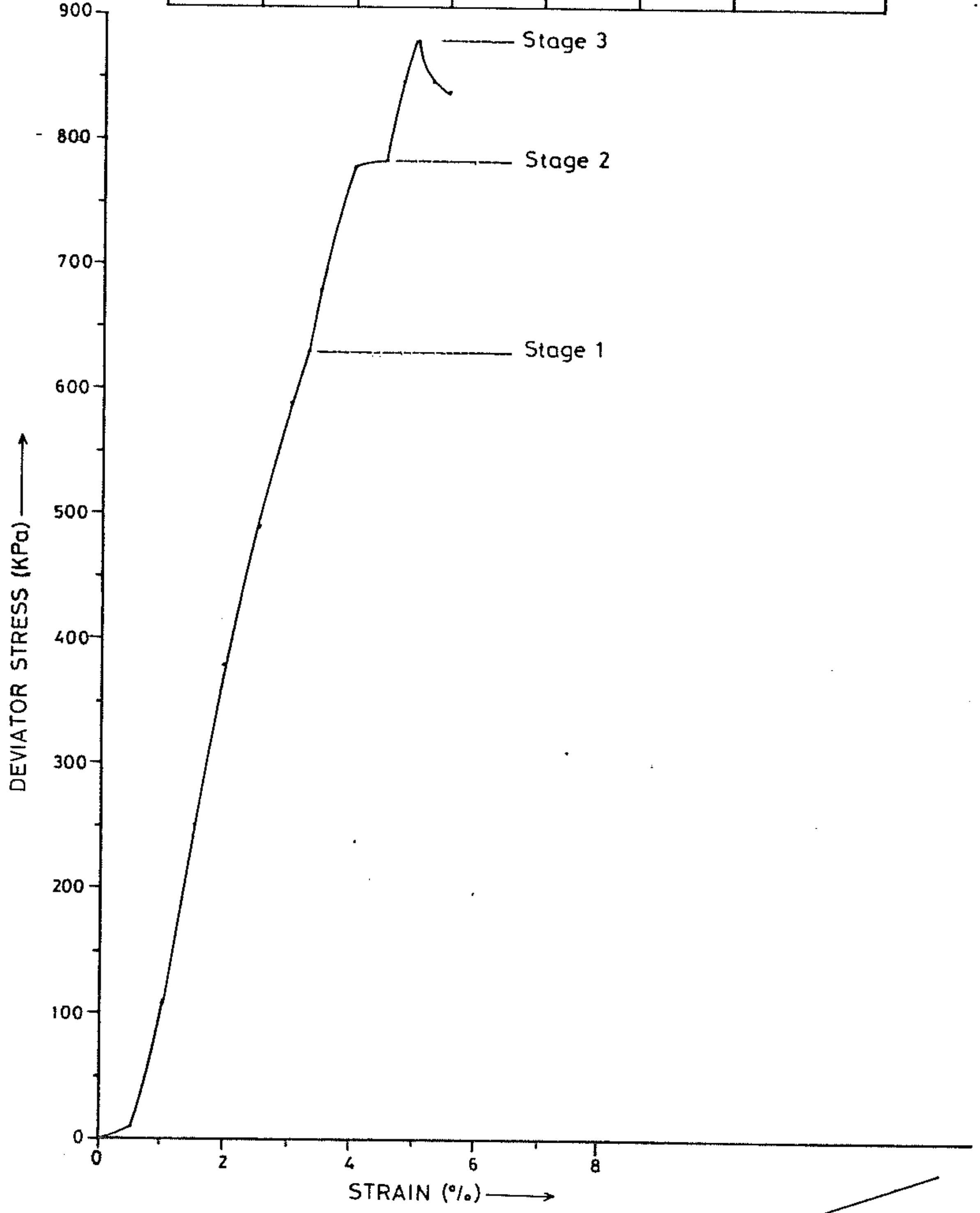


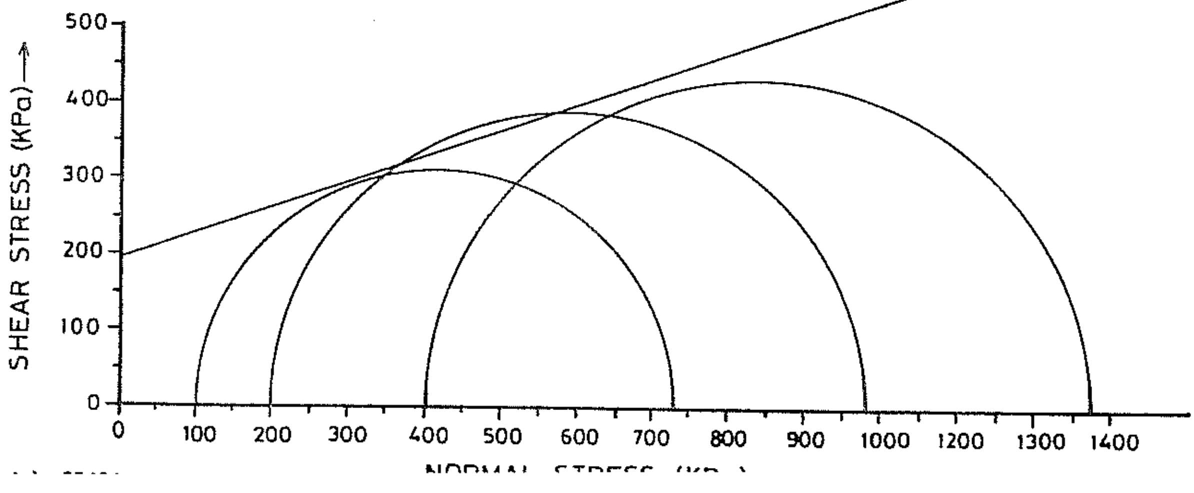
D. (E.Geol.) 79/83

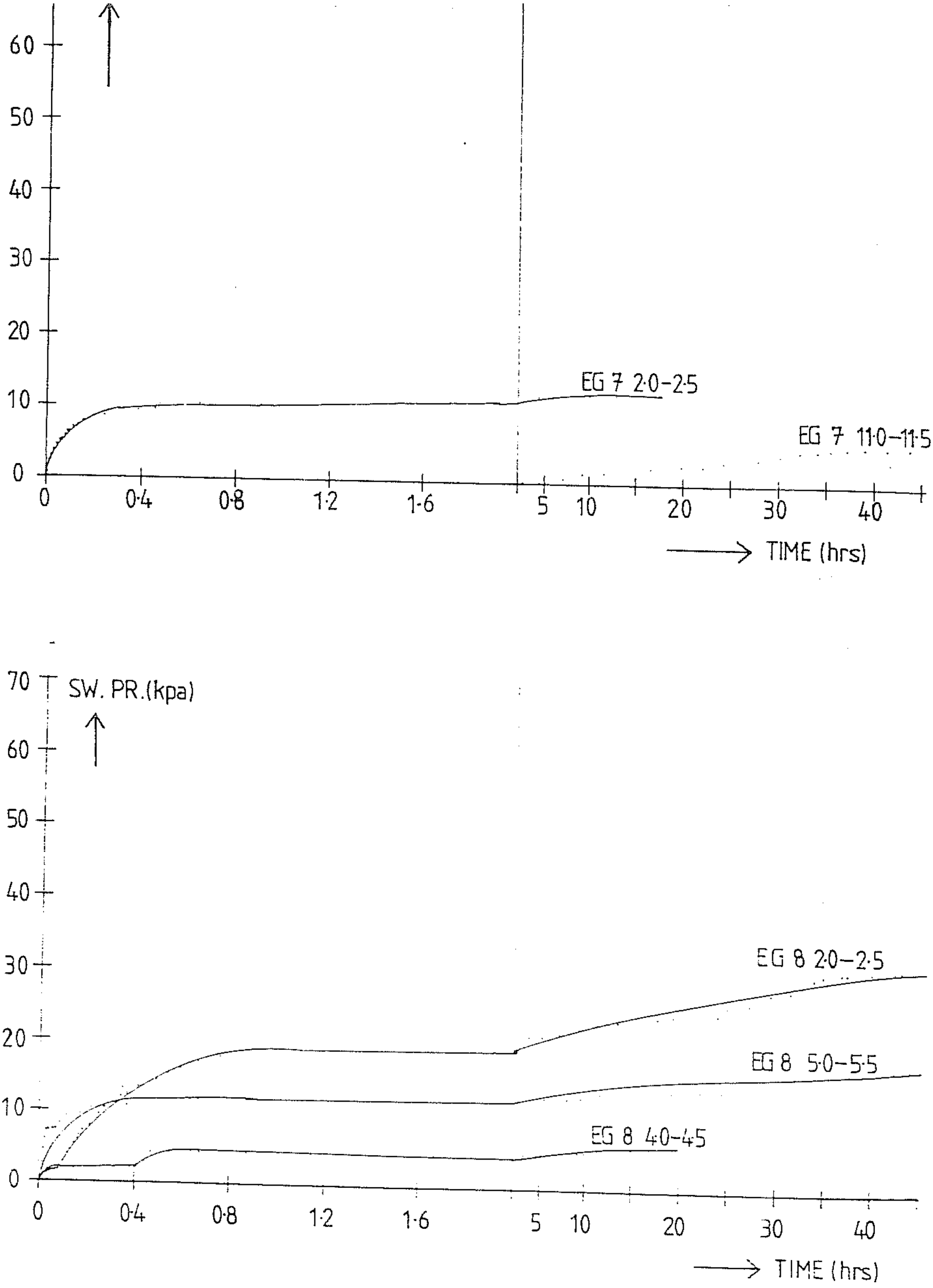
APP. 2.4

MULTISTAGE QU 100mm TRIAXIAL TEST

BH. No.	DEPTH (m)	Cu (KPa)	φu (degrees)	MOIST CONT. %	BULK DENSITY (Mg/m)	INITIAL TANGENT MODULUS (EI) (KPa)
EG. 18/82	11.0 – 11.5	195	19	29.40	1.89	25.000

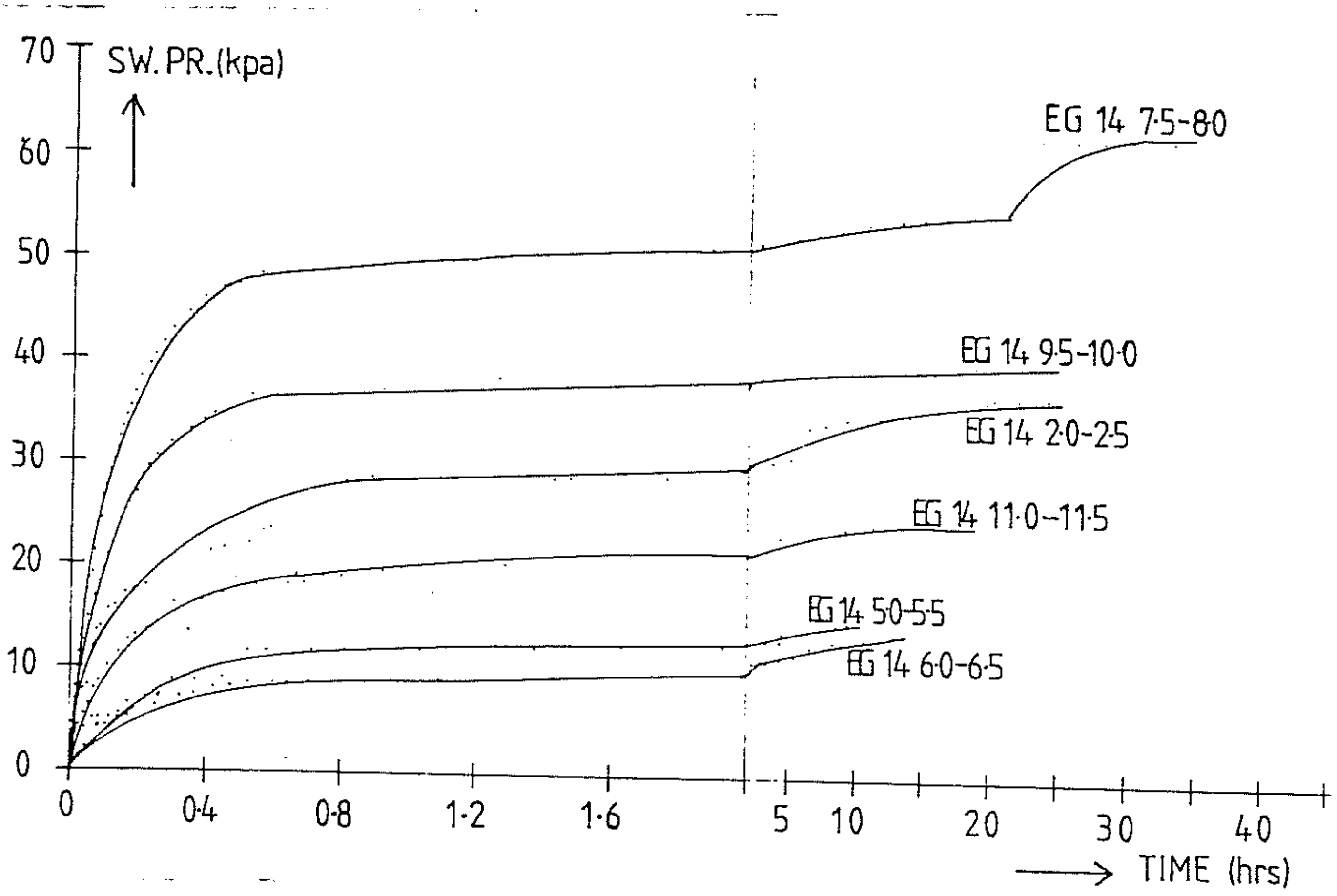


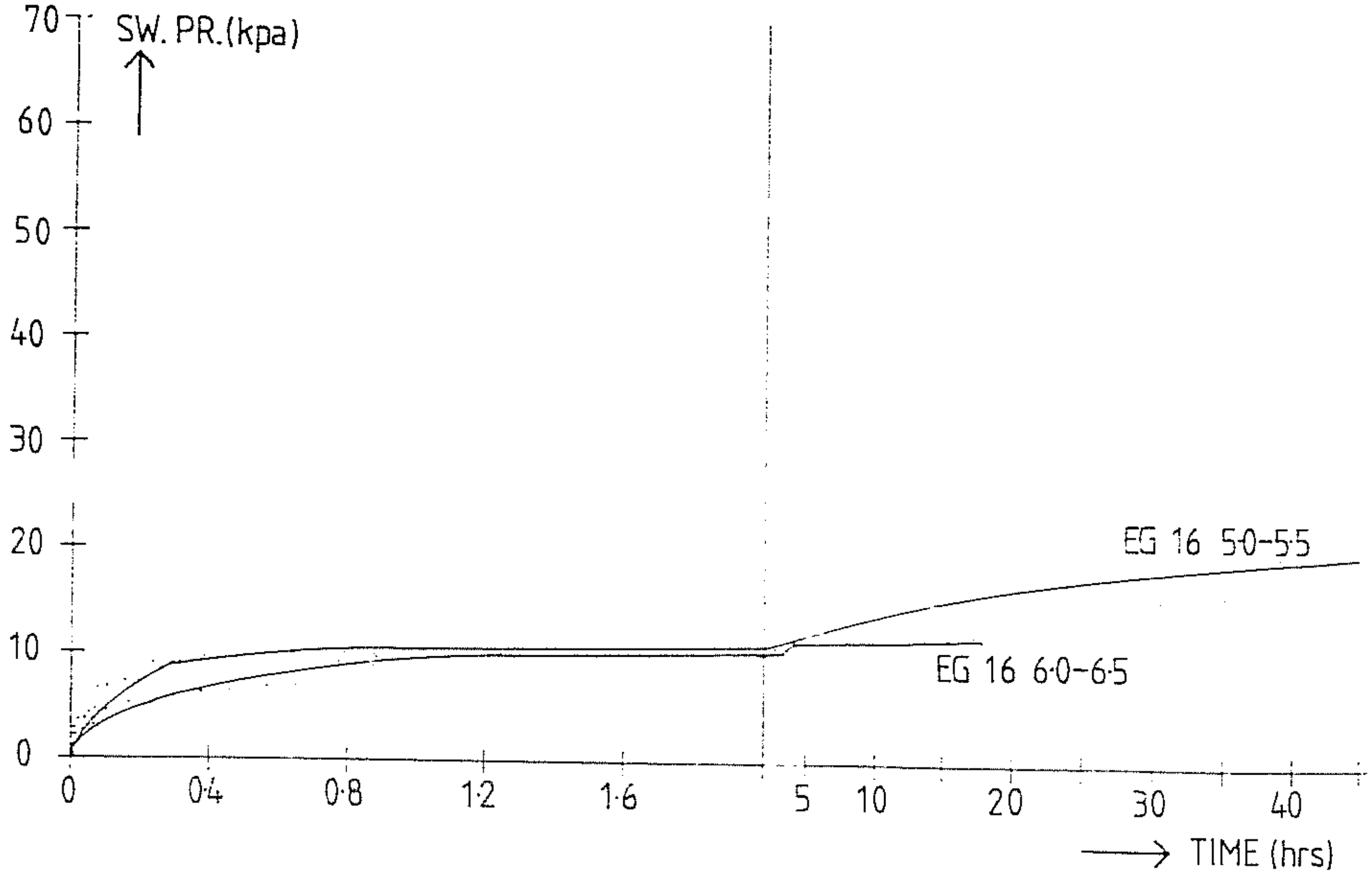




SWELLING PRESSURE v TIME

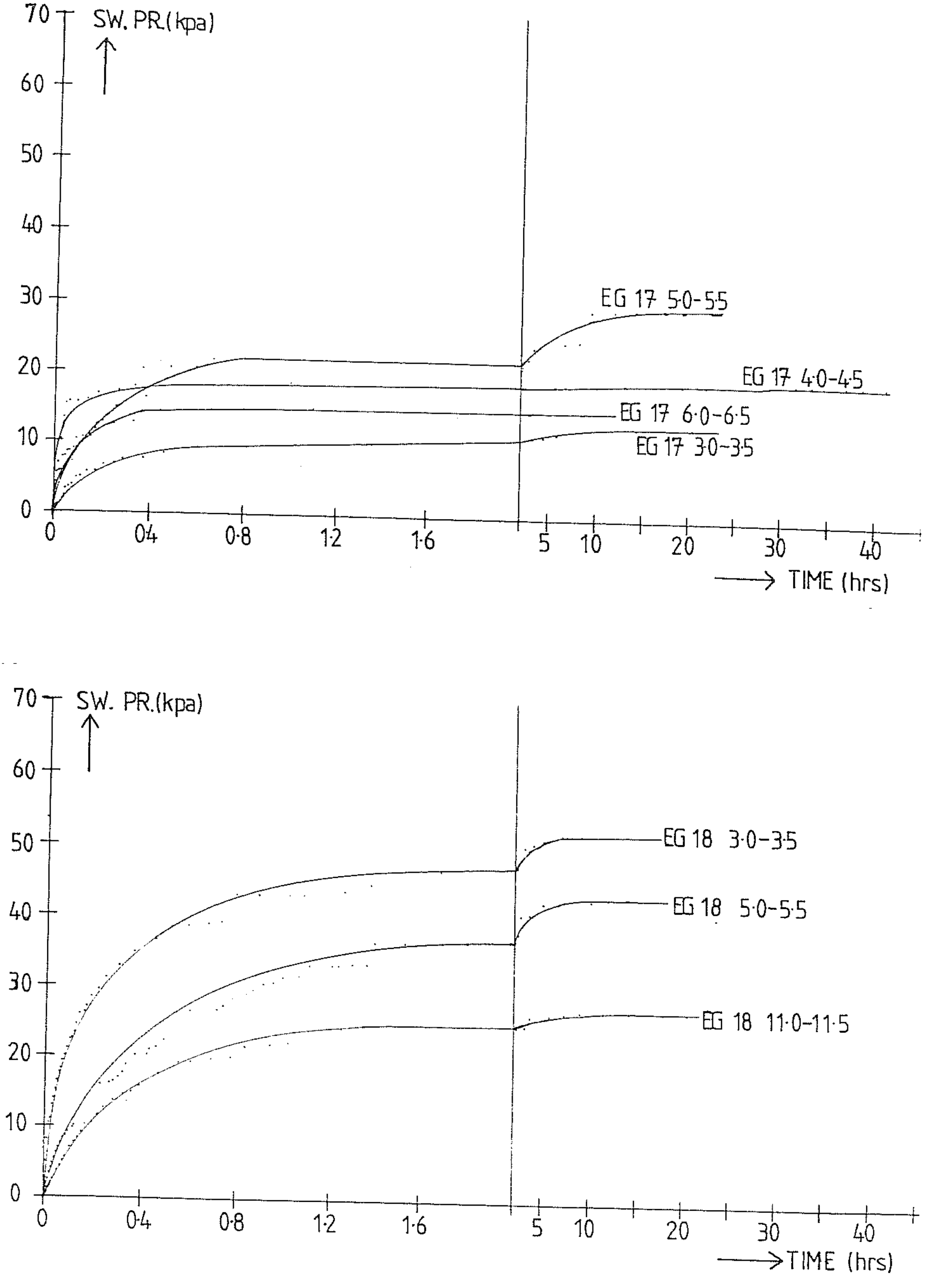
APP. 2.5





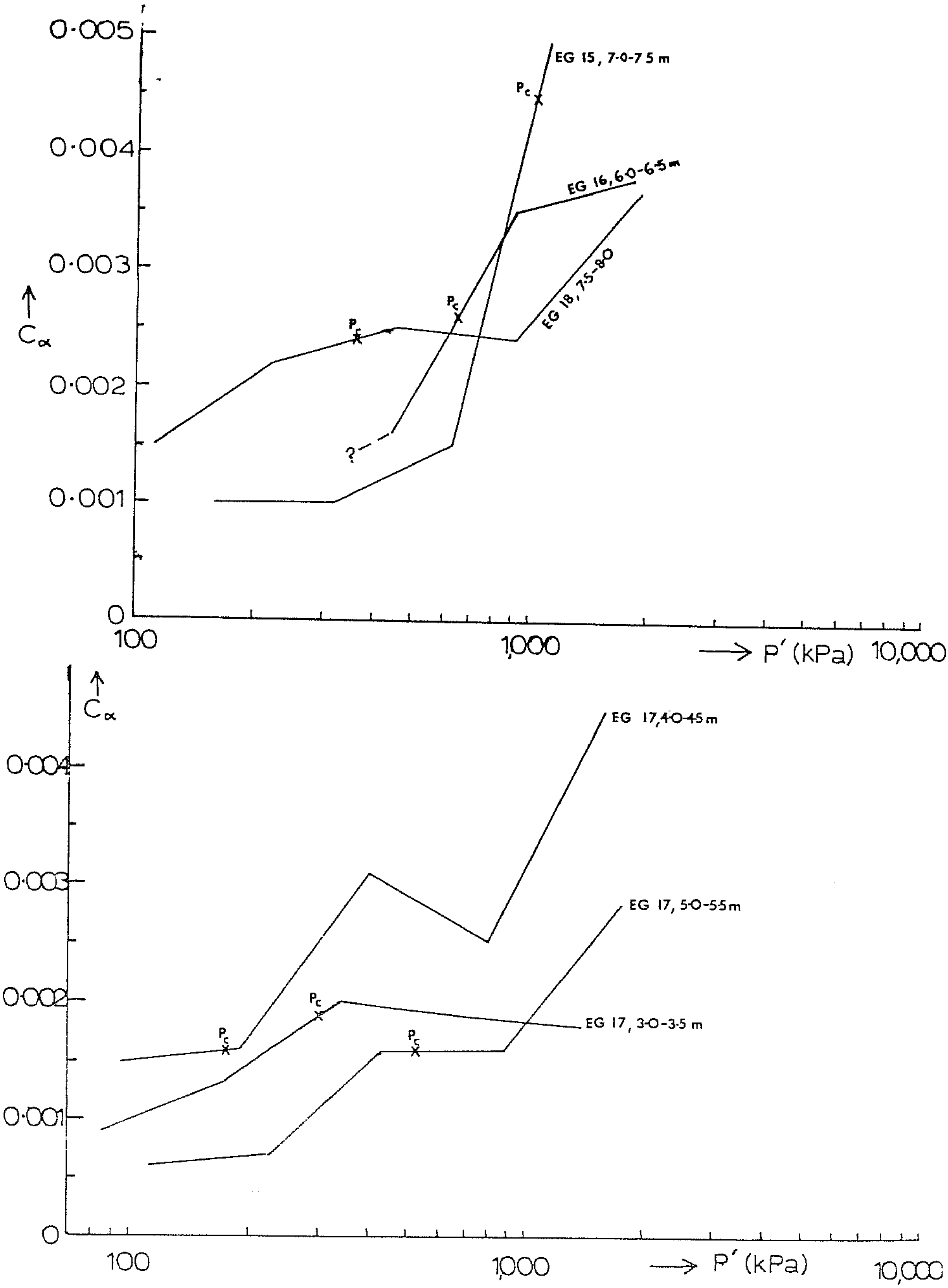
SWELLING PRESSURE v TIME

APP. 2.5



SWELLING PRESSURE v TIME

APP. 2.5

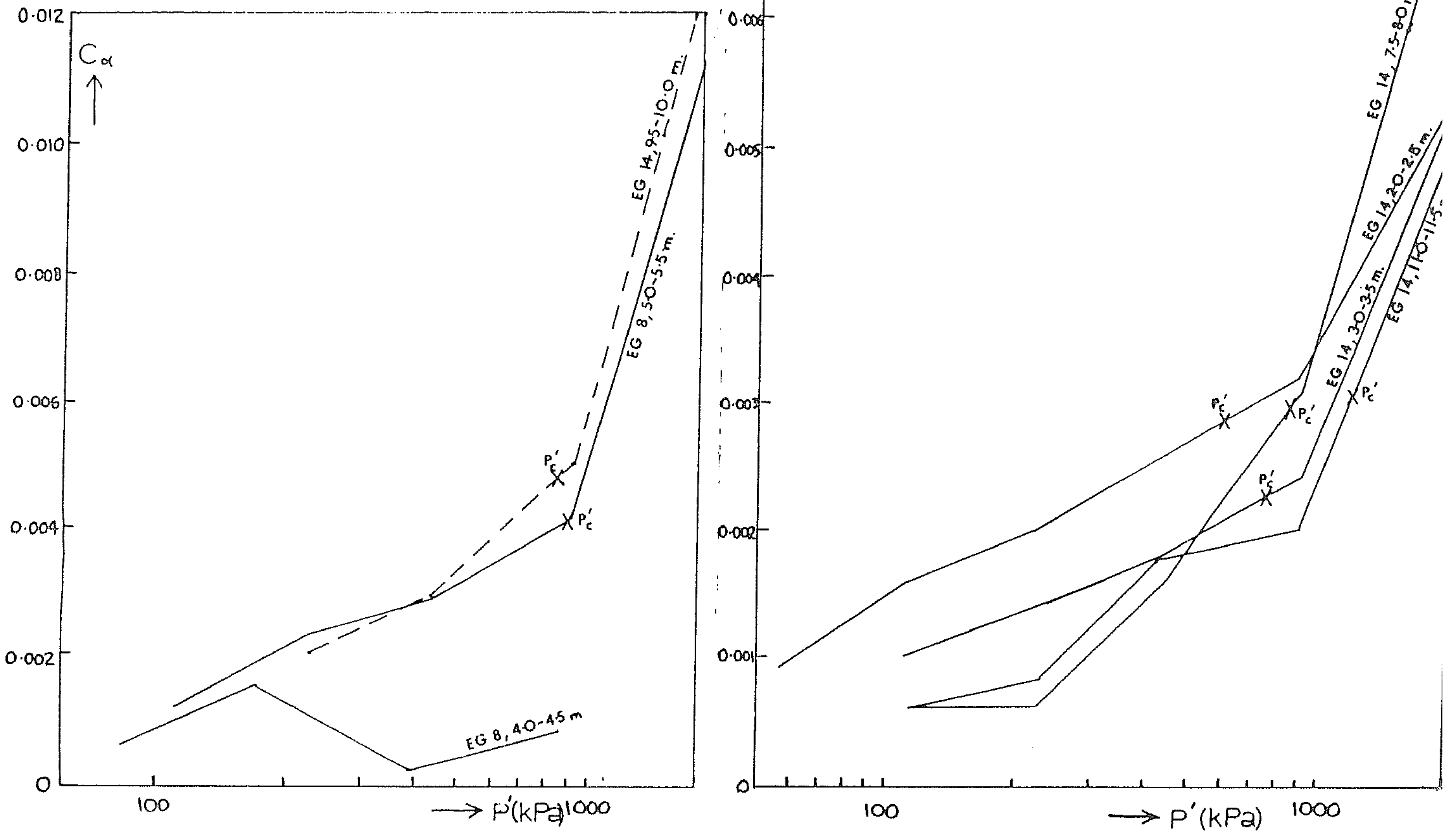


COEFF. of SECONDARY COMPRESSION v log P'

APP. 2.6

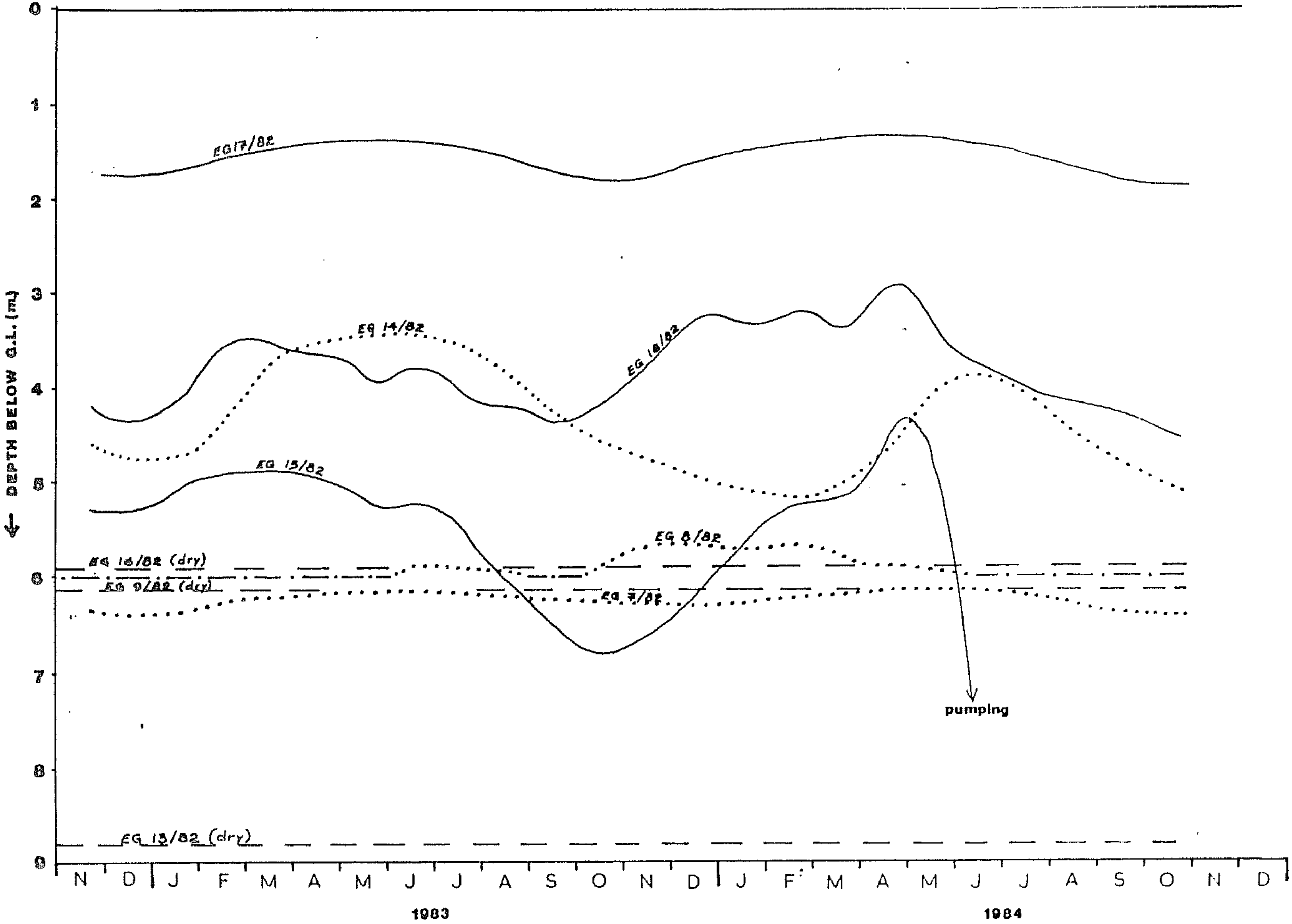
APP. 2.6

COEFF. of SECONDARY COMPRESSION (C_α) v log P′



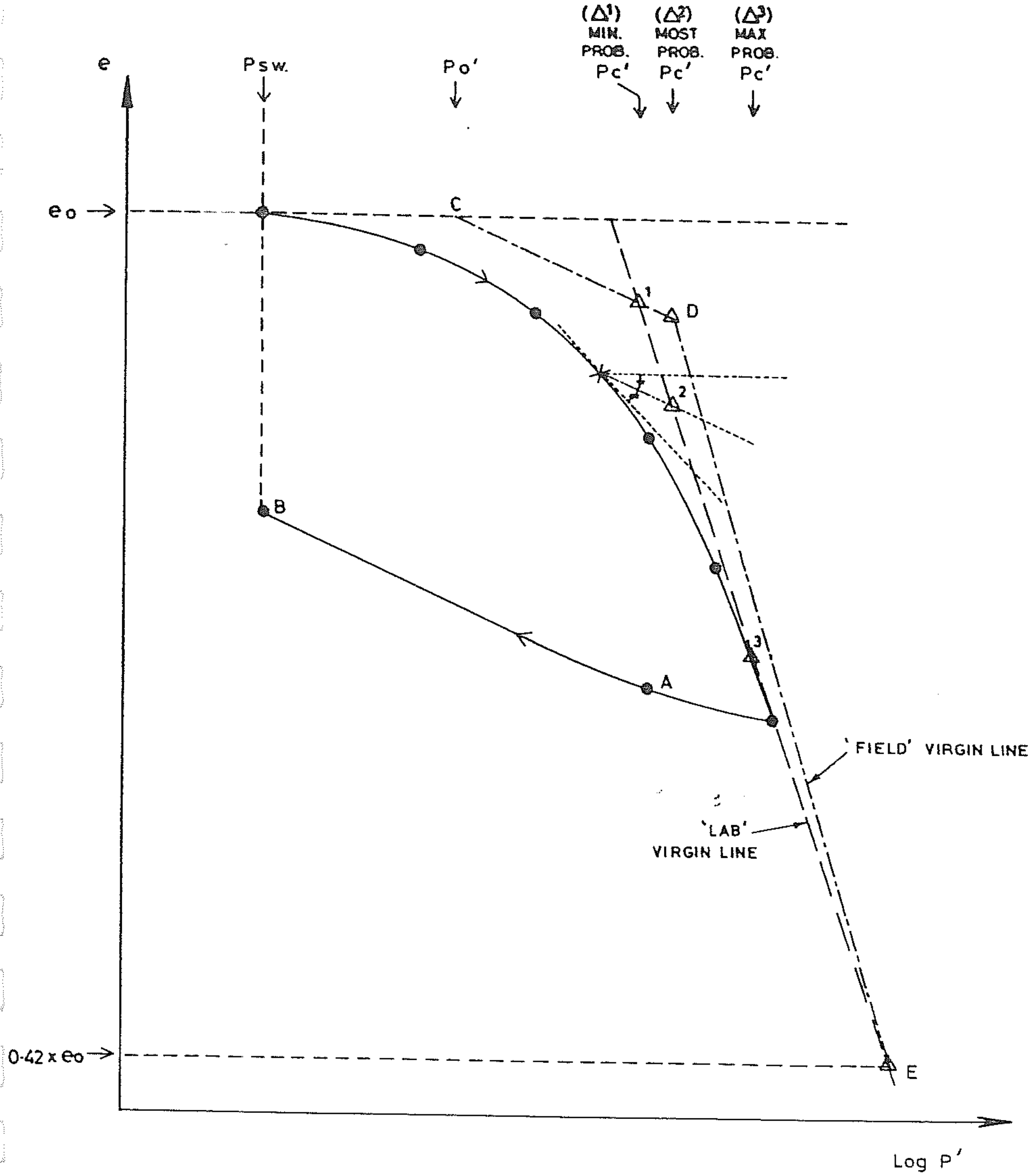
APPENDIX 3

BOREHOLE WATER LEVELS



APP. 3.1

EFFECTIVE PRESSURE CURVES TO OBTAIN OVERCONSOLIDATION RATIO AND FIELD CONSOLIDATION / REBOUND LINES



—·— 'SCHMERTMANN' CONSTRUCTION

------- 'CASAGRANDE' CONSTRUCTION

× POINT OF MAXIMUM CURVATURE

△ POINT OBTAINED BY GRAPHICAL CONSTRUCTION

Po' PRESENT EFFECTIVE OVERBURDEN

Psw INITIAL SWELLING PRESSURE

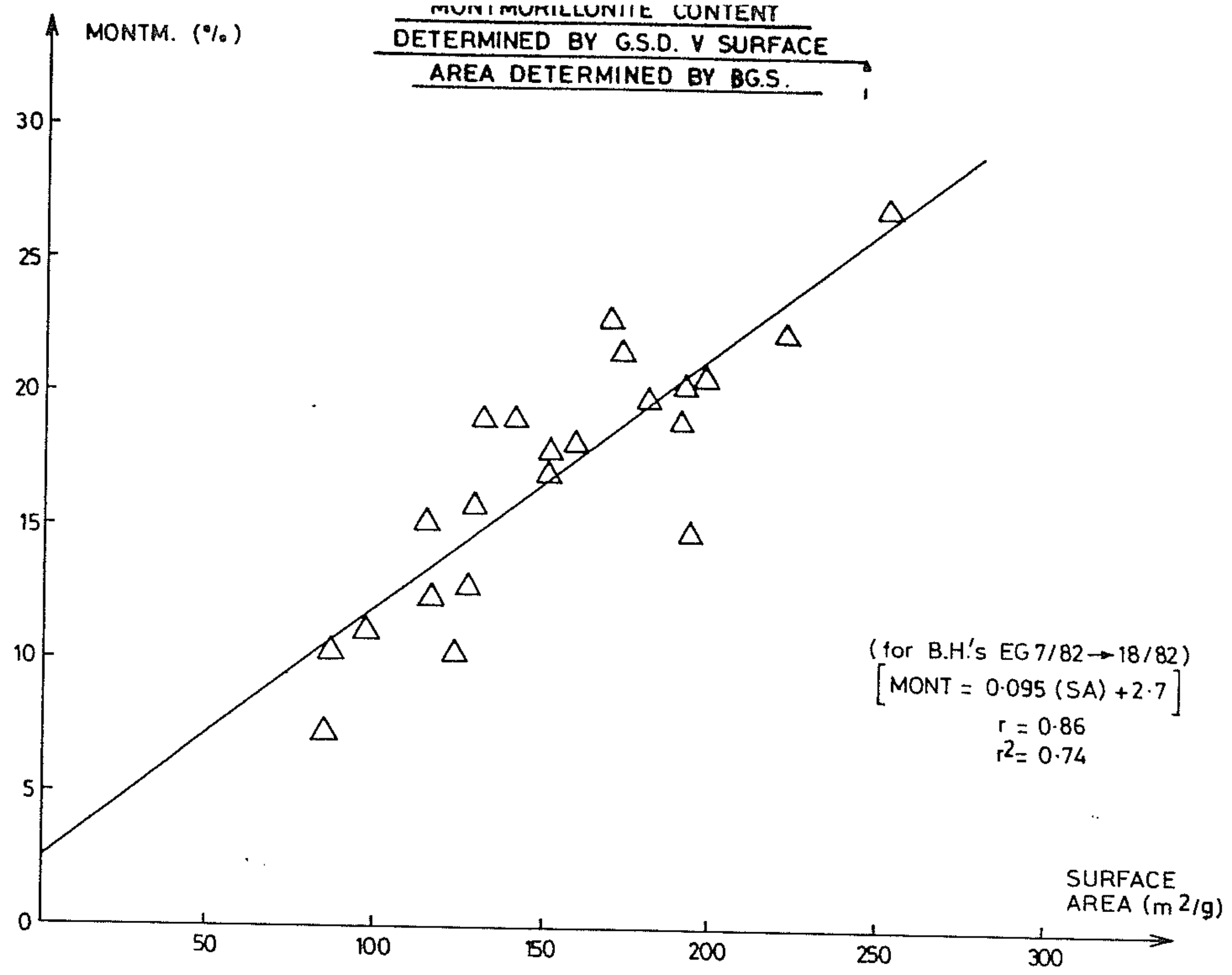
Pc' MAXIMUM PREVIOUS OVERBURDEN (OR 'PRECONSOLIDATION PRESSURE')

● INCREMENT OF LABORATORY LOADING / UNLOADING

→ LOADING CURVE (LABORATORY)

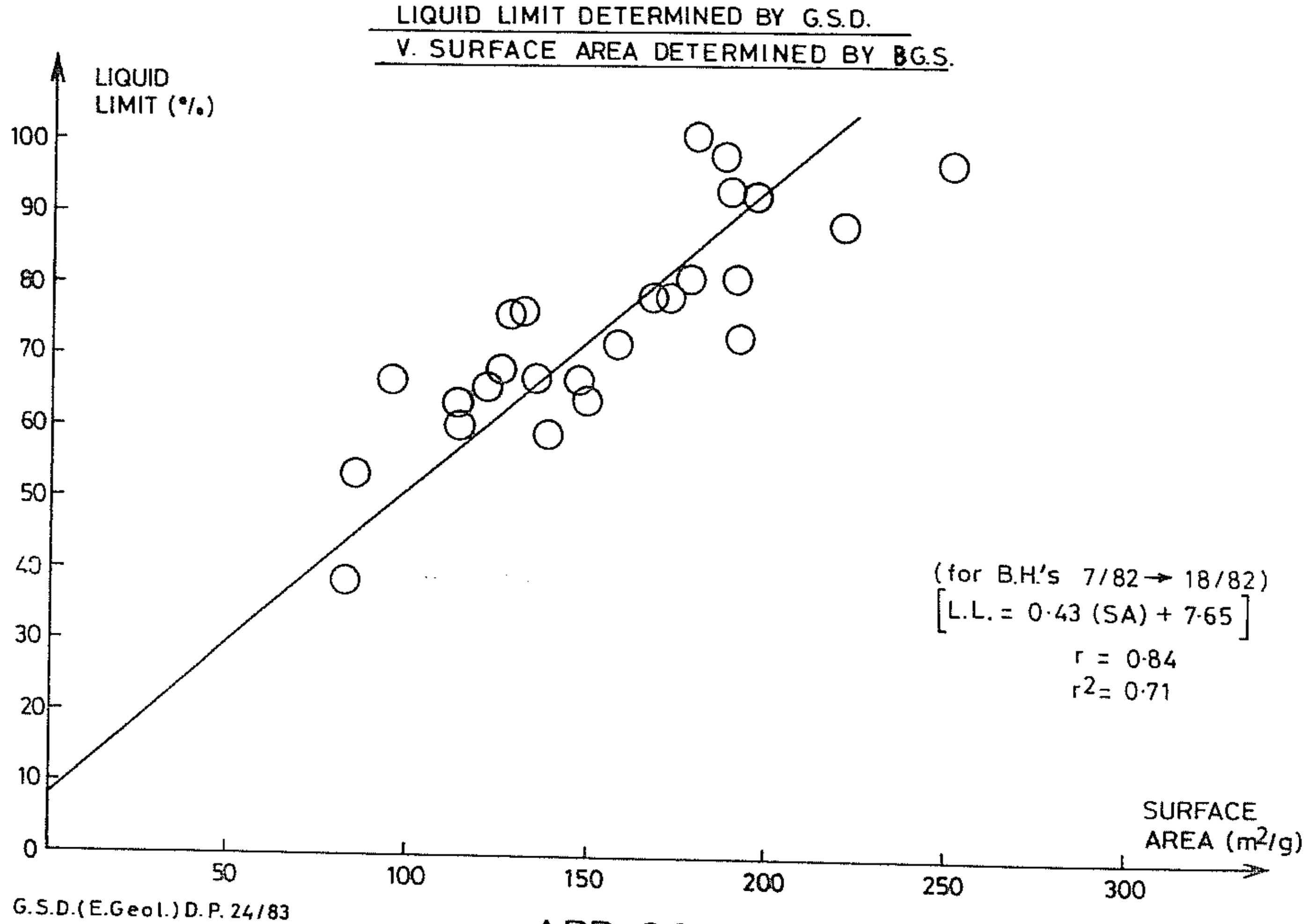
← UNLOADING CURVE (LABORATORY) OR REBOUND LINE

(LINE CD IS CONSTRUCTED PARALLEL TO LINE AB)



MONTMORILLONITE CONTENT
DETERMINED BY G.S.D. V SURFACE
AREA DETERMINED BY BG.S.

(for B.H.'s EG 7/82 → 18/82)
[MONT = 0·095 (SA) + 2·7]
$r = 0{\cdot}86$
$r^2 = 0{\cdot}74$

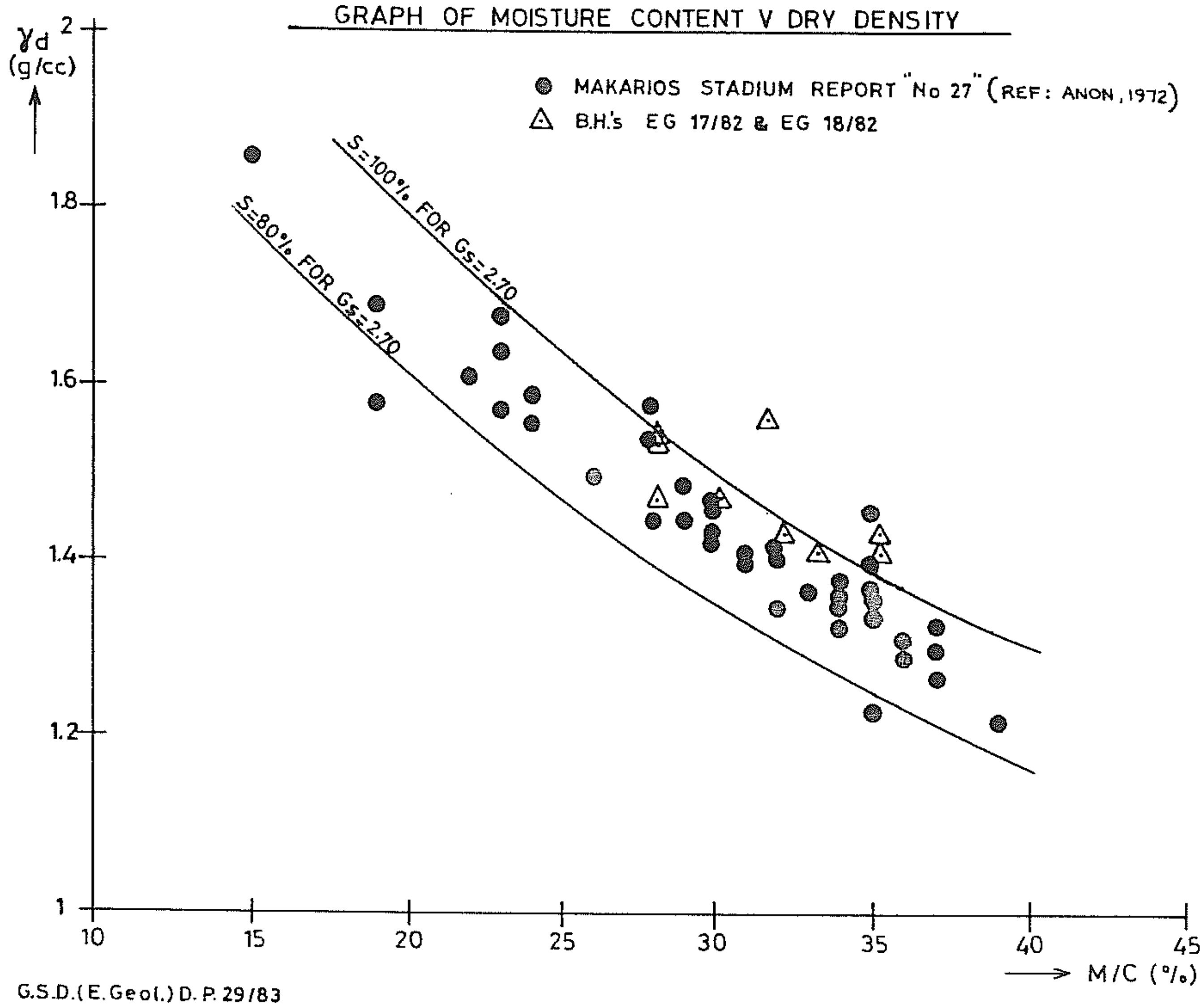


LIQUID LIMIT DETERMINED BY G.S.D.
V. SURFACE AREA DETERMINED BY BG.S.

(for B.H.'s 7/82 → 18/82)
[L.L. = 0·43 (SA) + 7·65]
$r = 0{\cdot}84$
$r^2 = 0{\cdot}71$

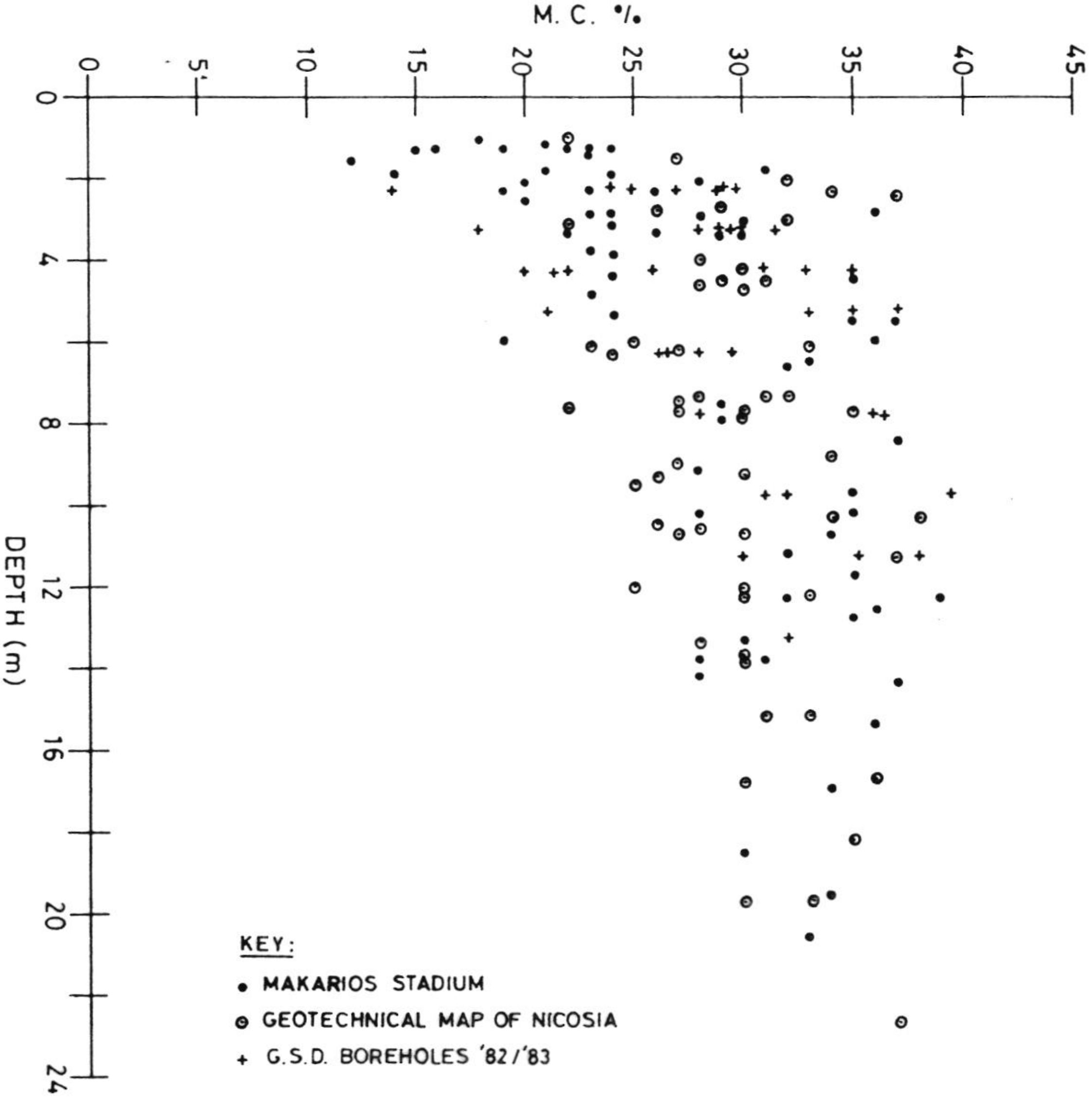
G.S.D.(E.Geol.) D.P. 24/83

APP. 3.3



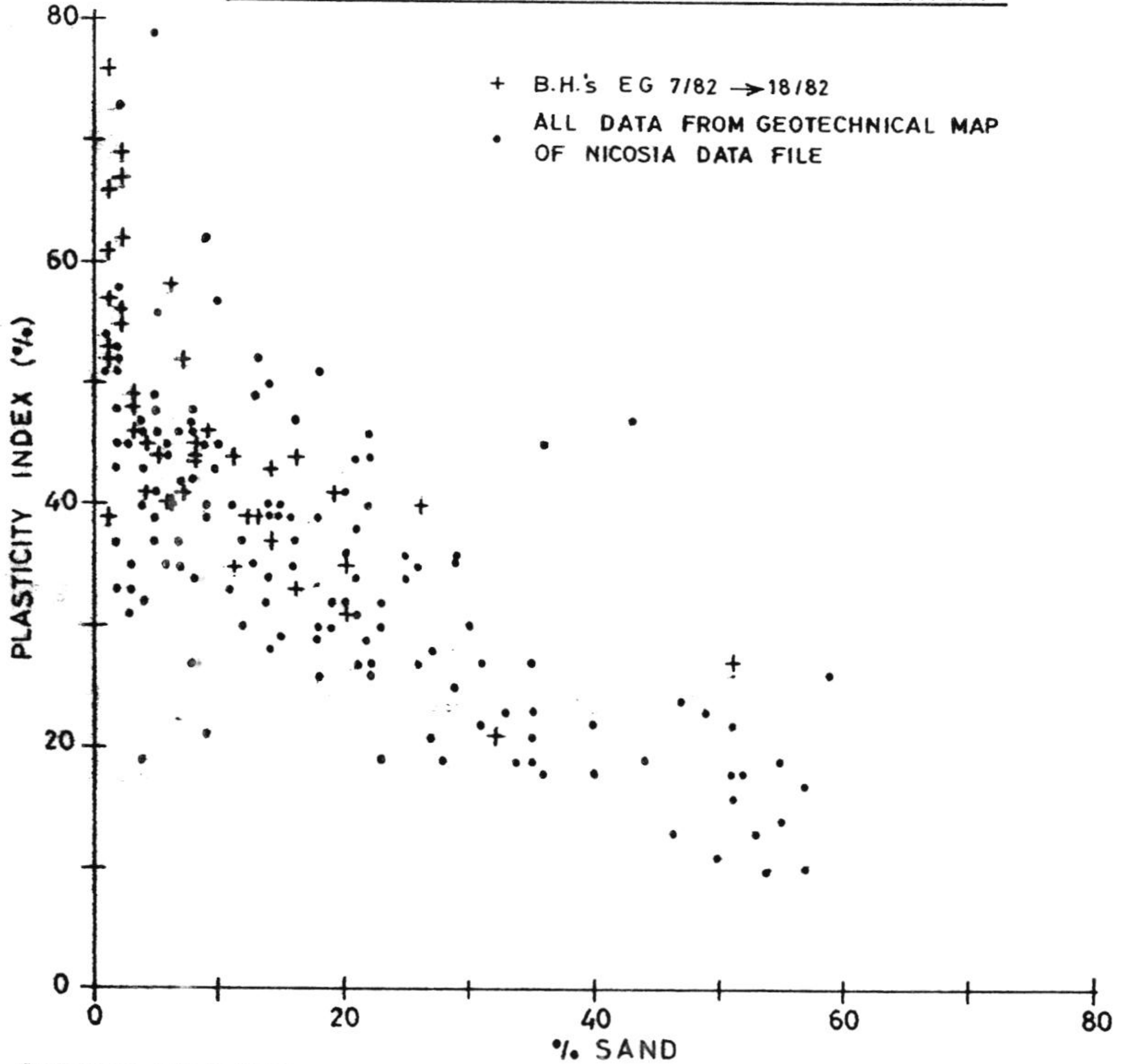
G.S.D.(E.Geol.) D.P. 29/83

APP. 3.4



MOISTURE CONTENT / DEPTH PROFILE
FOR ALL MARL DATA - NICOSIA

GRAPH OF PLASTICITY INDEX V SAND SIZE CONTENT



G.S.D.(E. Geol.) D. P. 28/83

APP. 3.6