British Geological Survey

Natural Environment
Research Council, UK

Geological Survey Department

Ministry of Agriculture & Natural
Resources, Cyprus

Report EGARP-KW/86/5
GSD Report G/EG/16
WN/RR/86/5

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

Supplementary geotechnical and mineralogical data for cohesive soil samples from selected sites across Cyprus

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Bibliographic reference

Charalambous, M., Hobbs, P. R. N., and Northmore, K. J., 1986. Supplementary geotechnical and mineralogical data for cohesive soil samples from selected sites across Cyprus: Engineering geology of cohesive soils associated with ophiolites, with particular reference to Cyprus. *Rep. EGARP Res. Group Br. Geol. Surv.*, No. EGARP-KW 86/5; *Rep. Geol. Surv. Cyprus*, No.G/EG/16.

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

EXECUTIVE SUMMARY

This report describes the general geological setting of Cyprus and the regional variations in lithological, geotechnical and mineralogical properties of the main cohesive soil formations (comprising marls, bentonitic clays, and 'melange') associated with the Troodos Ophiolite Complex. The report serves as an adjunct to more detailed 'study area' reports describing the Nicosia marls of central Cyprus; the Moni Formation bentonitic clays of S Cyprus; the Polis marls of NW Cyprus; and the Kannaviou Formation bentonitic clays, the Melange, and other cohesive deposits derived from allochthonous Mamonia Complex rocks in the Phiti-Statos area of SW Cyprus.

The report describes sample test data obtained from existing GSD surveys and from a collaborative BGS/GSD regional sampling and testing programme carried out as part of the study of Cyprus cohesive soils, where samples of the main cohesive soil formations were collected from selected sites across Cyprus to provide supplementary data 'external' to the main study areas.

A total of 122 'regional' samples were collected of which 100 were tested to determine geotechnical and mineralogical properties. The test data for each of the main cohesive soil formations are discussed in the report text and compared with test data from the main study area investigations. A summary listing of all supplementary results are listed in an appendix. A key map shows the location of the detailed cohesive soils project study areas, local GSD project areas, and supplementary regional sampling sites.

Classification of the Pliocene marls, using a simple triangular mineralogy plot and the standard Casagrande plasticity chart, has shown that the Nicosia marls of central Cyprus are generally more montmorillonitic, less calcareous, and less sandy than marl deposits elsewhere in Cyprus. The correspondingly more pronounced shrink-swell behaviour of these materials presents particular problems with regards to stability of open cuts and foundations subject to temporary or seasonal changes of moisture content.

The bentonitic clays of the Kannaviou, Perapedhi and Moni Formations show a wide range of plasticity values which, when plotted on the conventional Casagrande plasticity chart, fall on or near the A-line in a manner characteristic of inorganic clays of high to extremely high plasticity. The Moni clays of S Cyprus and the Perapedhi clays of SE Cyprus are shown to possess generally higher montmorillonite contents and tend to occupy the higher (extremely plastic) end of the plasticity scale. The best-fit line for the Casagrande plot data has been found to diverge from the A-line at high values of liquid limit (i.e. the increase of plasticity index with increasing liquid limit is greater than

expected).

Limited index data from regional localities outside the main study areas tend to indicate that the Kathikas Melange of SW Cyprus is a geotechnically uniform deposit comprising clays of intermediate to very high plasticity with montmorillonite contents averaging c.20%. Local variation is related to the dominant Mamonia source rocks from which this deposit is derived. Mass engineering behaviour is however, likely to be influenced by variations in clast content and shear zones related to 'recent' landslipping.

Cohesive soil deposits derived from weathered stratified (sedimentary) Mamonia rocks, although lithologically similar to the Kathikas Melange, are characterized by more 'granular' (less plastic) soil characteristics; with local variations in both geotechnical and mineralogical properties reflected by rapid and often marked changes in bedrock lithology.

Finally, the report highlights the uncertainties in attempting to assess regional variations in geotechnical properties based on comparison and extrapolation of data from individual study areas and sampling localities.

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1. INTRODUCTION

The collabarative research programme between the Geological Survey Department (GSD) of Cyprus and the British Geological Survey (BGS) commenced in 1981 with the geotechnical mapping and data assessment of the greater Nicosia area, (south of the UN 'Green Line', established since 1974). The outcome of this initial work was the publication, in 1982, of the Geotechnical Map of Nicosia.

Collaborative research in Cyprus continued with the present study concerned with the engineering geology of cohesive soils associated with ophiolites.

In general terms, ophiolites are widely accepted as representing land-bound fragments of deep ocean crust, comprising a distinct assemblage of basic and ultrabasic rocks. In accordance with plate tectonics theory, their emplacement occurs near subduction zones at destructive plate boundaries adjacent to continents and island arcs, i.e. in zones of complex tectonic stresses.

In Cyprus, the cohesive soil formations occur in close proximity to the Troodos Ophiolite and include material derived, wholly or in part, from sub-marine or sub-aerial erosion of these rocks and/or from complex allochthonous rock formations emplaced by large scale gravity slides along an active continental margin. The cohesive soils are comprised largely of 'bentonitic' (montmorillonite) clays which undergo marked shrinking and swelling when wetted and dried. Where the cohesive marine sediments have been subjected to a complex stress-strain history, they may be extensively sheared.

In the 'Cyprus Cohesive soils project', emphasis was placed on the engineering geological study of the marl, bentonitic clay and 'melange' deposits. Within this framework, a geotechnical investigation of the Pliocene marls in the Nicosia area was undertaken in 1982/3, followed in 1983/4, by a geotechnical study of the Pliocene marls in the Polis region of

NW Cyprus and the 'tectonised' bentonitic clays of the Moni Formation in the Pendakomo area, Southern Cyprus.

In 1984 the project was broadened to include a detailed engineering geological investigation of two adjacent study areas in the Paphos region of SW Cyprus, where extensive outcrops of Kannaviou Formation bentonitic clays, 'Melange' and other cohesive deposits derived from allochthonous Mamonia Complex rocks are involved in widespread mass movements.

Initial investigations in the Paphos region began with a detailed geological and geotechnical survey of a 40 km^2 area centred on the village of Phiti (Study Area 1), and included aerial photographic assessment, 1:5000 scale geological and engineering geological field mapping, surface sampling, exploratory boreholes and pits, and extensive mineralogical and geotechnical laboratory testing. This was followed in 1985 with the geological and geotechnical appraisal of a second, adjacent area of 63 km^2 centred on the village of Statos (Study Area 2). As with Area 1, the survey was based on an assessment of aerial photography, field mapping, surface sampling and laboratory testing, but with subsurface investigations restricted to limited exploratory pitting. The two study areas form a continuous survey area located adjacent the western margin of the updomed Troodos Massif, with Area 2 contrasting with Area 1 by virtue of its higher elevation, steeper relief, and extensive outcrops of Mamonia Complex rocks. Both areas are characterized by widespread slope instabilities.

In addition to the main study areas noted above (i.e. Nicosia, Polis, Pendakomo and Paphos Study Areas 1 and 2) a number of supplementary samples from the main cohesive soil formations found elsewhere in Cyprus were collected and tested. Samples and test data available in the Geological Survey Department of Cyprus, from earlier local projects, were also collated, assessed, and supplemented where necessary with additional geotechnical and mineralogical tests.

The present report aims to summarise these supplementary data available in GSD, or obtained within the framework of the collaborative Cohesive Soils Project, with respect to their regional variation in lithological, mineralogical and geotechnical properties.

The supplementary regional sampling and testing programme formed the final phase of the project study and entailed the collection and assessment of Pliocene marl, bentonitic clays of the Kannaviou Formation, and 'melange' associated with the Mamonia Complex rocks, from selected sites across Cyprus. It is noted here that facies variations result in marked lithological differences in the bentonitic clay formations found in the Paphos study area and elsewhere in Cyprus. Also, the rocks of the Mamonia Complex, the main source rocks of the 'melange', occur extensively in the Paphos region outside Study Areas 1 and 2.

The results of the main study area investigations are presented in a series of reports detailed in Section 3.2. This report forms the last in the series.

2. GENERAL GEOLOGICAL SETTING

A simplified geological map of Cyprus is shown on Fig.1.

The geological formations have been grouped into four main units:

a) The Troodos ophiolite
b) The circum-Troodos sedimentary succession
c) The Pentadaktylos succession
d) The Mamonia Complex

These units occur in four slightly arcuate, E-W trending zones.

The northernmost zone is represented by the Pentadaktylos (or Kyrenia) range. Immediately to the south, the Mesaoria Plain is underlain by the circum-Troodos sedimentary rocks. A major tectonic zone (the Ovgos fault zone) runs across the Mesaoria basin, geologically separating the relatively undisturbed circum-Troodos sedimentary rocks to the south and the highly folded and faulted deposits of the Pentadaktylos succession to the north.

The south - central zone of Cyprus is dominated by the Troodos Ophiolite which forms the structural and morphological backbone of the island. Circum-Troodos sediments occur round its periphery.

The fourth zone, in southwest Cyprus, is occupied by the allochthonous rocks of the Mamonia Complex.

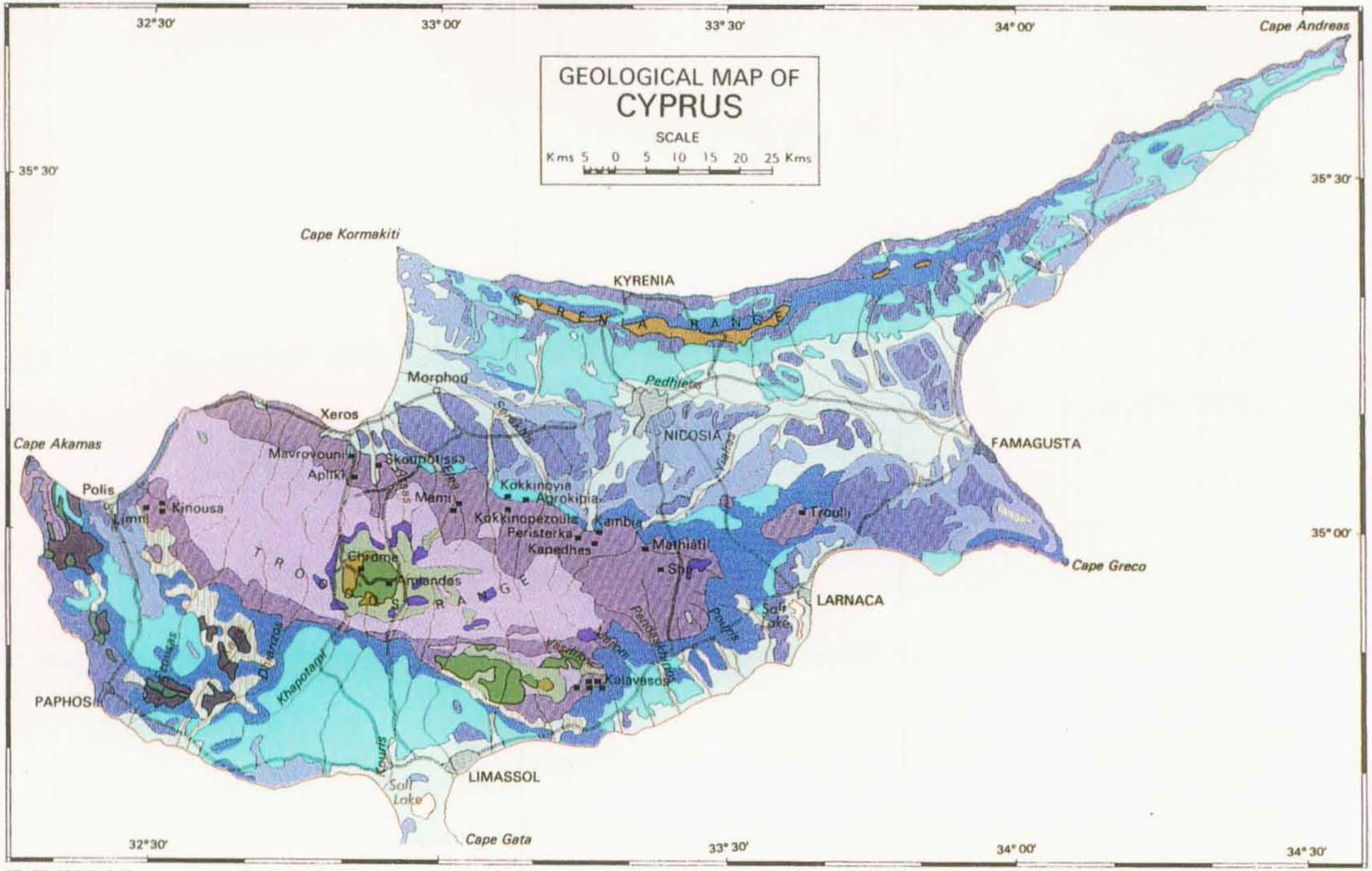
2.1 The Troodos ophiolite

The Troodos ophiolite,thought to be pre-Campanian in age, consists of a sequence of ultramafic rocks (pyroxenite, wehrlite, dunite, harzburgite and serpentinite) overlain by gabbros, plagiogranites, sheeted dykes and pillow lavas. These rocks comprise the main Troodos Massif which forms an elongated, E - W orientated dome centred on Mount Olympus. Tertiary uplift (thought to be the result of serpentinization of the mantle rocks) and subsequent erosion of the massif, has resulted in exposure of the deepest stratigraphic units in the central, highest part of the dome with the younger extrusive units arrayed concentrically around them forming the mountain foothills.

2.2 The circum-Troodos sedimentary succession

The circum Troodos sedimentary succession comprises a number of geological formations ranging in age from Campanian to Recent.

The base of the sequence is marked by the Perapedhi Formation of Campanian to Early Maastrichtian age, which



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LEGEND

SEDIMENTARY FORMATIONS

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

TROODOS OPHIOLITE (PRE-CAMPANIAN)

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

Fig. 1

consists of layers of umbers, radiolarites and radiolarian mudstones resting unconformably on the pillow lavas of the Troodos Complex.

The Kannaviou Formation, of Maastrichtian age, conformably overlies the Perapedhi Formation and comprises a sequence of bentonitic clays, mudstones and shales interbedded with volcaniclastic sandstones and siltstones. It is a thick, extensive deposit in south and southwest Cyprus, whilst around the north and northeast perimeter of the Troodos Complex it is restricted to scattered, thin deposits of bentonitic clays.

In S and SW Cyprus, distinct circum Troodos deposits occur that are related to the emplacement and submarine erosion of the Mamonia allochthonous rocks. In the Limassol district of southern Cyprus, a sedimentary melange unconformably overlies the rocks of the Troodos Complex. This distinctive deposit contains blocks of almost all the Mamonia Complex lithologies embedded in a matrix of highly disturbed and tectonically sheared, greenish-grey clay of the Kannaviou Formation. In the present study, this melange is referred to as the 'Moni Formation' as defined by Swarbrick and Robertson (1980). In SW Cyprus, the 'Kathikas Formation', a sedimentary melange distinct in origin from the Moni Formation, discontinuously overlies parts of the Mamonia Complex, the Kannaviou Formation and the Troodos Complex. The Kathikas melange consists of numerous clasts of Mamonia rocks strewn through a matrix of reddish silty clay and differs strongly in stratigraphical position, internal organization and composition from the Moni melange of S Cyprus.

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

The Pliocene is represented by the Nicosia Formation comprising marl and subordinate arenitic deposits, overlain by the Athalassa Formation of Pleistocene age consisting mainly of arenitic deposits (calcarenites) and marls.

The upper parts of the circum Troodos sedimentary succesion are represented by Pleistocene Fanglomerates and Terrace Deposits of sand, silt and gravel. Finally, Holocene alluvium deposits are present throughout Cyprus.

2.3 The Pentadaktylos succession

The Pentadaktylos succession forms a distinctive assemblage of rocks forming the Pentadaktylos (or Kyrenia) Range. The sequence starts with the Carboniferous-Permian Kantara Formation, the Triassic Dhikomo and Sykhari Formations, and the Jurassic Hilarion Formation. These formations are all represented by largely allochthonous limestones and marbles.

Resting unconformably on the above sequences are a series of autochthonous formations. The lowermost Lapithos Formation (Maastrichtian-Eocene) comprises limestones, marl, chert and lavas. This is successively overlain by the Ardana-Kalogrea Formation (Oligocene-Lower Miocene) incorporating breccias, marl, grit and greywacke, and the Kythrea and Pakhna Formations (Middle Miocene) consisting of alternating chalk, marl, marly chalk, and arenites, and greywacke, marl, sandstone, siltstone and basal conglomerate. The succession ends with Pleistocene and Recent deposits of silts, sands and gravels.

[It should be noted that the sediments of the Pentadaktylos succession in N Cyprus were not investigated as part of the 'cohesive soils' study owing to their location within the Turkish occupied area.]

2.4 The Mamonia Complex

The Mamonia Complex of SW Cyprus comprises a diverse assemblage of allochthonous, highly deformed Triassic to Lower Cretaceous sedimentary, igneous and subordinate metamorphic rocks which were emplaced on Troodos during the Maastrichtian. The complex crops out extensively throughout SW Cyprus and along the perimeter of the Troodos complex in S Cyprus (as the Moni Formation sedimentary melange, discussed in Section 2.2, above). Where present, the Mamonia Complex rocks wedge between the Kannaviou Formation or the Troodos Ophiolite and the Lefkara Formation.

The Mamonia Complex has been the subject of extensive disscussion in the recent literature and various ideas related to its origin, mode of emplacement and stratigraphical classification have been reported. The most significant of these are discussed extensively in Report No. KW/86/4 (this series). For additional information regarding the Mamonia Complex rocks, reference may be made to the bibliography presented in the same report.

The Mamonia Complex rocks may be divided into two main geological units or groups (each group may be subdivided into subsidiary formations or members which are not detailed here).

The lower (basal) group comprises igneous and sedimentary rocks of Triassic-Jurassic age, consisting mainly of extrusive and minor intrusive rocks with alkaline affinities, reef limestones and hemipelagic sediments.

The upper group is entirely sedimentary, consisting mainly of thin-bedded radiolarian cherts, siltstones, mudstones, limestones, calcarenites and quartz sandstones. This group has been referred to as the 'stratified' Mamonia in the current study.

Other formations not included in the two main groups comprise olistostrome melange (i.e. the Moni and Kathikas melanges, noted previously), and slivers of metamorphic rocks and serpentinite sheets which are tectonically associated with the basal igneous-sedimentary group.

3. THE COHESIVE SOILS SURVEY, SAMPLING AND TESTING

3.1 The Survey Areas

A summary lithological map of Cyprus is shown in Fig. 2. On this map the major geological formations are grouped together and emphasis placed on the cohesive soil deposits, which are mainly represented within the circum Troodos sedimentary succession.

The Troodos Ophiolite Complex, the Pentadaktylos succession and the Mamonia Complex are shown on the map (Fig. 2) as distinct, but undifferentiated, units.

The circum Troodos sedimentary rocks are divided into four groups:

a) Cemented and uncemented superficial deposits, related to the Fanglomerate, Terrace deposits and Alluvium formations.

b) The marls with subordinate gypsum, calcarenites and marly chalks, related to the Athalassa, Nicosia and Kalavasos Formations.

c) The chalks, calcarenites and limestones, with subordinate marls, related to the Koronia, Pakhna, Terra and Lefkara Formations.

d) The group incorporating umbers, radiolarites, bentonitic clays, volcaniclastic sandstones and 'melange' which are related to the Perapedhi, Kannaviou, Moni and Kathikas Formations.

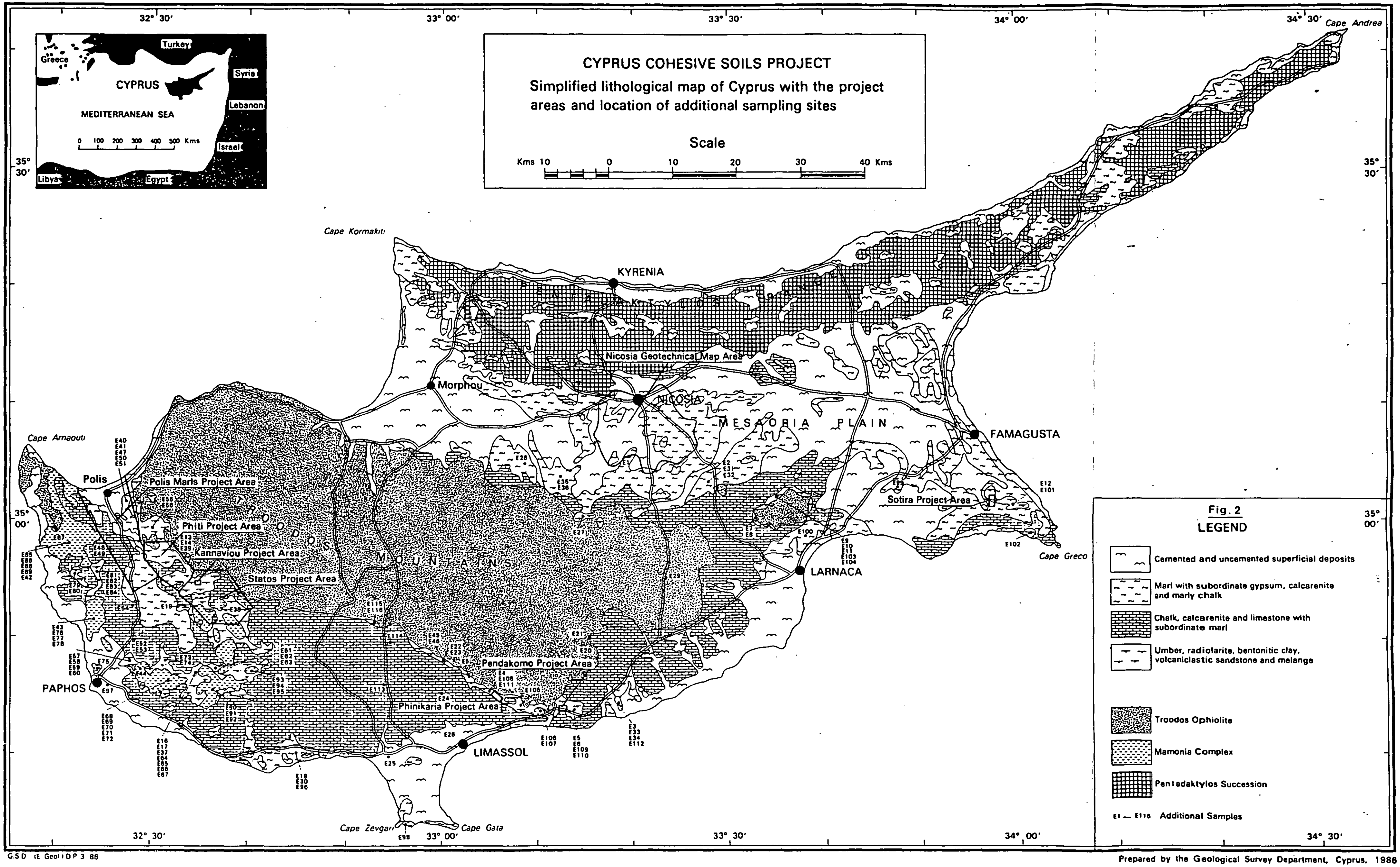


FIGURE 2. Simplified lithological map of Cyprus showing location of main project study areas and supplementary sampling sites.

Table 1

Relationship between the stratigraphy and the summary units used in Fig. 2.

	Stratigraphical divisions	Summary litho-stratigraphy
CIRCUM TROODOS SEDIMENTARY SUCCESSION	Alluvium	Cemented and uncemented superficial deposits
	Terrace deposits	
	Fanglomerate	
	Athalassa	Marl with subordinate gypsum,calcarenite and marly chalk
	Nicosia	
	Kalavasos	
	Koronia	Chalk, calcarenite and limestone with subordinate marl
	Pakhna	
	Terra	
	Lefkara	
	Moni	Umber, radiolarite bentonitic clay, volcanoclastic sandstones and melange
	Kannaviou	
	Perapedhi	
TROODOS OPHIOLITE	Volcanic Complex	Troodos Ophiolite
	Sheeted Intrusive Complex	
	Plutonic Complex	
MAMONIA COMPLEX	Sedimentary	Mamonia Complex
	Igneous and Sedimentary	
	Serpentinites	
	Metamorphics	
PENTADAKTYLOS SUCCESSION	Kantara	Pentadaktylos Succession
	Dhikomo	
	Sykhari	
	Hilarion	
	Lapithos	
	Ardana-Kalogrea	
	Pakhna/Kythrea	

The relationship between the stratigraphical divisions and the summary lithological and stratigraphical groupings used on map Fig. 2 is shown in Table 1.

3.2 The sampling

During the Cyprus Cohesive Soils Study, examples of all the main cohesive soil formations were sampled with the exception of those related to the Pentadactylos succession. The samples, and subsequent mineralogical and geotechnical test data, were obtained during the course of investigations carried out in five main study areas, and from regional sampling at selected sites across Cyprus. Regional data were also supplemented by additional samples and test results obtained from other relevent local GSD projects.

The locations of the main cohesive soil project study areas, local GSD project areas, and regional sampling sites are shown on Fig. 2.

The five main project study areas are those of Nicosia, Polis, Pendakomo, and the Phiti and Statos areas in the Paphos region.

The Nicosia and Polis study areas are underlain mainly by the Pliocene marls of the Nicosia Formation. The relevant geological, mineralogical and geotechnical data pertaining to these deposits are presented in report Nos. EGARP KW/86/1 and KW/86/3 (this series).

The Pendakomo study area is located within the outcrop of highly disturbed bentonitic clay/melange of the Moni Formation. This deposit was investigated in detail at a selected unstable road cut on the Nicosia-Limassol highway. The results of this study are given in report No. EGARP KW/86/2,(this series).

The Phiti and Statos study areas in SW Cyprus were investigated in detail by means of field mapping, exploratory boreholes and pit excavations. Extensive sampling and laboratory testing was carried out on cohesive sediments that included bentonitic clays of the Kannaviou Formation, Kathikas Melange, and those derived from the weathering of the sedimentary (stratified) Mamonia Complex rocks. The results of these studies are presented in report No. EGARP KW/86/4.

The Sotira, Phinikaria and Kannaviou project areas (Fig. 2) are located within outcrops of bentonitic clays. These areas were investigated by the Geological Survey Department as part of a study to assess these clay deposits in terms of their economic use in the ceramics industry and in commercial exploitation of bentonite. Relevant project data were taken into consideration in the regional mineralogical/geotechnical assessment of these deposits presented in this report.

A total of 122 bulk surface samples from the main cohesive soil formations (i.e. marls, bentonitic clays, melange and deposits derived from weathered sedimentary, or stratified, Mamonia rocks) were collected from selected supplementary regional sites across Cyprus. The numbers of samples obtained from each site are shown on Fig. 2 by listings of their allocated registration code (e.g. E16, the 'E' prefix indicating the sample is 'external' to the main study areas).

3.3 Testing

Laboratory geotechnical and mineralogical tests were carried out on the disturbed samples collected during the regional survey.

Geotechnical testing involved the determination of basic index test parameters, i.e. Atterberg Limits (plastic limit, PL; and liquid limit, LL), Plasticity Index (PI), and particle size analyses. Thirteen ring-shear tests were carried out to determine residual shear strength values.

Mineralogical testing included the measurement of total carbonate ($CaCO_3$), montmorillonite and quartz contents, and X-ray diffraction analysis, to determine mineralogical composition, was undertaken on virtually all samples.

Geotechnical test procedures were carried out in accordance with British Standards BS 1377:1975, and mineralogical testing in accordance with procedures laid down in standard texts. Descriptions of test methodologies are described briefly in the reports on the main study area investigations (in particular, report Nos. EGARP KW/86/1 and KW/86/4) and are not repeated here.

4. RESULTS

4.1 Geotechnical test results

Geotechnical test results are listed in the Appendix.

4.1.1. Kannaviou, Moni and Perapedhi Formations

The supplementary regional sampling localities for the bentonitic clay formations (Kannaviou, Moni and Perapedhi) may be divided into four areas for the purposes of geotechnical comparison:-

a) the Paphos-Polis area (W and SW Cyprus)
b) the Pendakomo-Apsiou area (to the NW, NE & N of Limassol)
c) the Troulli and Kambia areas (to the NW of Larnaca)
and d) the Paralimni area (SE Cyprus).

All samples with the exception of six from Pendakomo (B.H.s 10/82 & 11/82, Pendakomo) are surface samples taken from outcrop. Test results from these four areas are plotted on a Casagrande plasticity chart (Fig. 3) and an Activity chart (Fig. 4) with data from the Phiti and Statos study areas (see Report No. EGARP/KW/86/4) also shown for comparison. The

FIG. 3

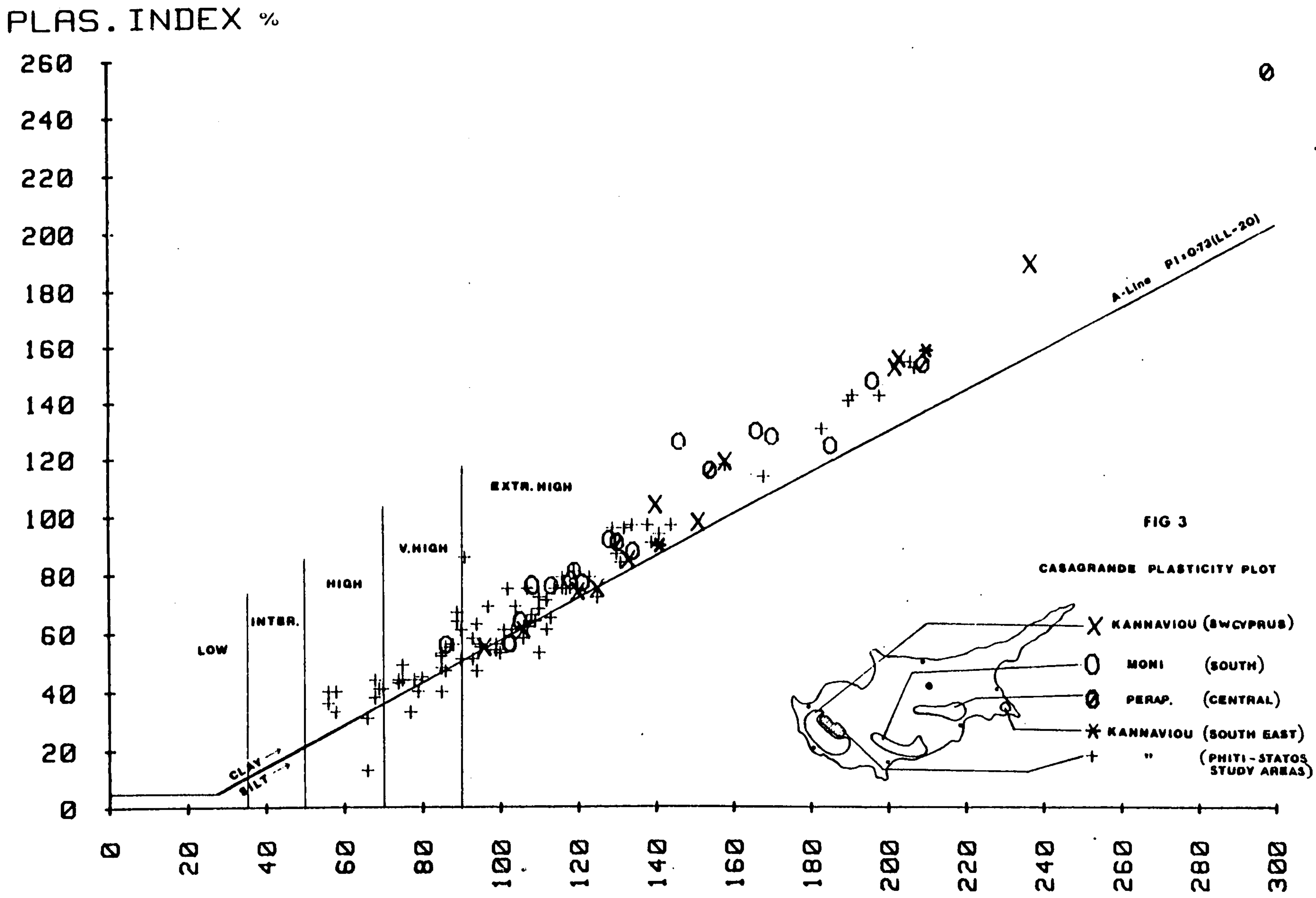


Fig. 3 Casagrande Plasticity plot -Kannaviou, Moni & Perapedhi formations

FIG.4

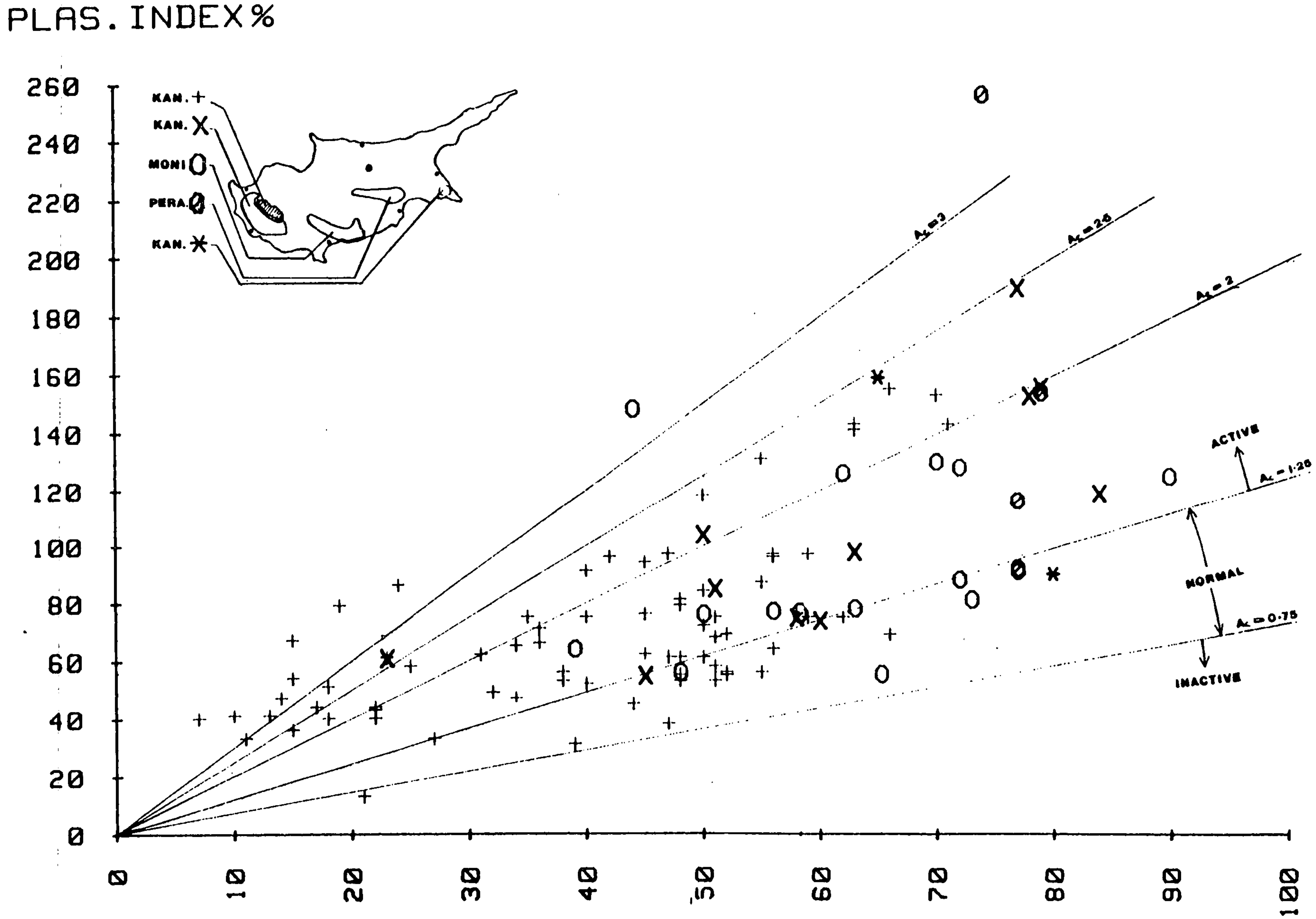


Fig. 4 Plasticity index v clay fraction - Kannaviou, Moni & Perapedhi formations

plasticity chart shows a wide spread of points for all the four areas. However, it can be seen that the supplementary bentonitic clays from S and SE Cyprus occupy the higher end of the plasticity scale (extremely plastic) and correspond to the more plastic of the Phiti-Statos samples. This may be explained in part by differences in representative sample selection, but more probably reflects the influence of extensive volcaniclastic sandstone and siltstone sequences developed in SW Cyprus. This arenaceous material would tend to impart slightly more 'granular' (less plastic) soil characteristics to parts of the associated clay deposits in this region.

The trend observed in the Activity (Ac = P.I./ %CLAY) plot (Fig. 4) is for the bentonitic clays of S and SE Cyprus to have generally similar activities to the majority of samples from the Phiti-Statos study areas, despite the generally higher clay contents of the former.

Values of Activity (i.e. the slope of the P.I./ %CLAY graph) for the supplementary samples mostly fall in the range Ac = 1 to Ac = 2.5 (i.e. normal to highly active); two samples (E11 and E21), both of which are highly bentonitic clays, exhibit Activities in excess of 3. Again, no regional trend is discernible in the data. The relationship between montmorillonite content and plasticity index is shown in Fig. 5. A reasonably good correlation is seen, with an indication that plasticity indices increase rapidly for montmorillonite contents greater than about 50%.

The bentonitic clays at Pendakomo in S Cyprus, near the Limassol - Nicosia highway, are currently quarried for commercial bentonite. The Ca-montmorillonite-rich clays are treated with sodium carbonate and made into pellets. Other suitable quarry sites on Kannaviou, Moni and Perapedhi clay outcrops have been investigated with a view to commercial exploitation.

Few natural moisture content (m.c.%) determinations were

FIG. 5

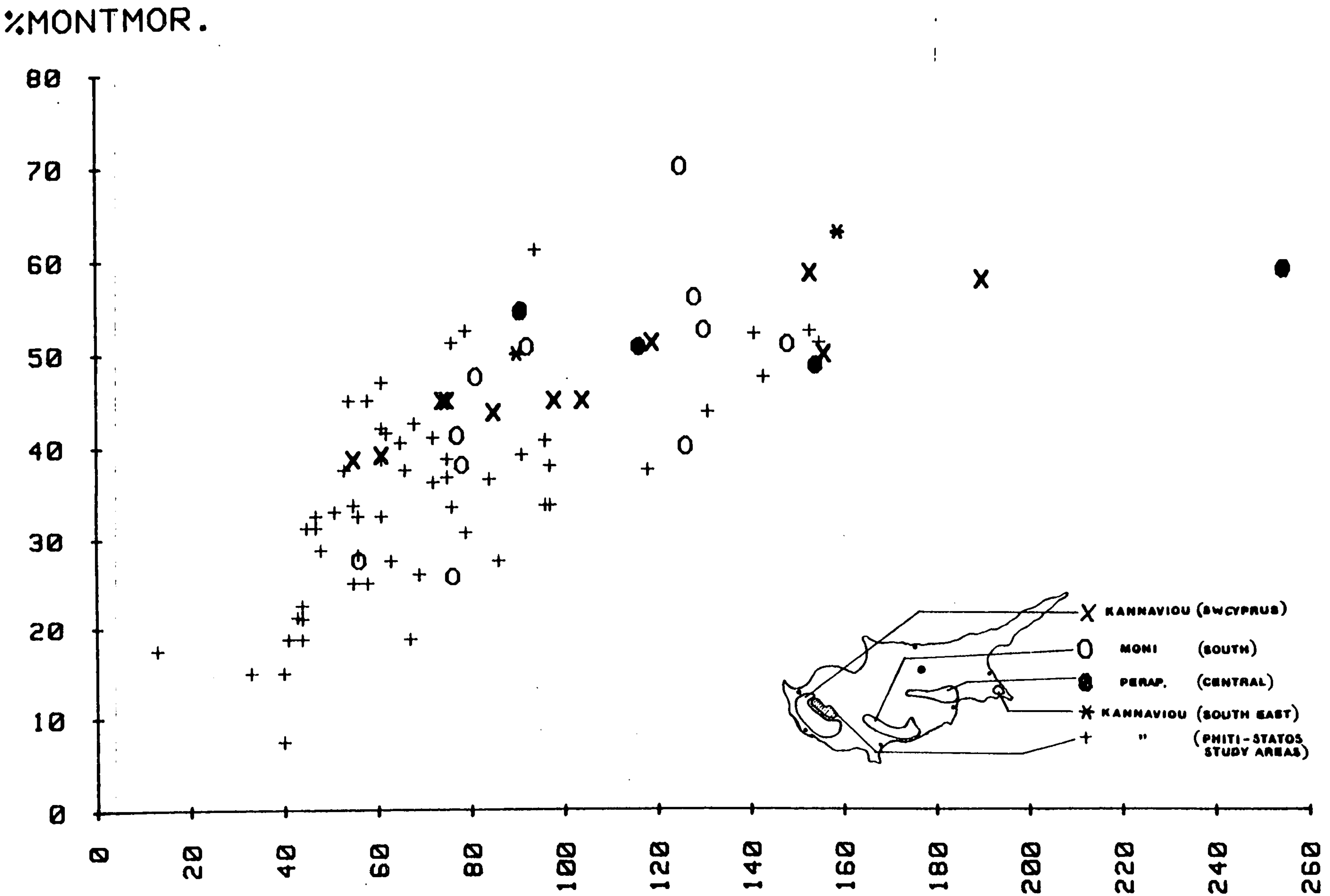


Fig. 5 Montmorillonite content v plasticity index - Kannaviou, Moni & Perapedhi formations

made. Indications are, however, that the bentonitic clays are overconsolidated and exhibit negative values of Liquidity Index (defined as (m.c.% - PL) / PI).

The bentonitic clays of the Moni Formation melange examined in the Pendakomo study, possess a penetrative shear fabric represented by closely-spaced, randomly orientated, slickensided discontinuities (Report No. EGARP KW/86/2). Further examination of Moni clays in the Pendakomo quarry has also revealed large scale 'undulating' shear zones which tend to divide the clay mass into lens-shaped bodies. Zones of closely spaced, irregular, slickensided shear discontinuities have also been found at certain horizons within the Kannaviou bentonitic clays in SW Cyprus (Report No. EGARP KW/86/4). These shear structures are almost certainly tectonic in origin and related to the emplacement of the allochthonous Mamonia Complex. The presence of shear discontinuities has a marked influence on the settlement and stability of engineering structures, foundation excavations and cut slopes, and in areas where natural slopes and hydraulic gradients are steep, may be a controlling factor in the distribution of deep-seated landslides.

Drained residual shear strength values were measured in the laboratory using the Bromhead ring-shear apparatus. The results show a general decrease in residual frictional strength, mr^1, with increasing montmorillonite content. At higher montmorillonite contents the residual strengths may be extremely low, e.g. samples E11 and E17 exhibit the mr^1 values of only 9.5^o and 7.9^o respectively, with corresponding montmorillonite contents of 55% and 58%. These values represent the minimum strength that one might expect as a result of total remoulding at high moisture contents or along pre-existing shear surfaces. All test samples showed a decrease in mr^1 value with increasing normal effective stress (e^1); this normal-stress dependency is particularly pronounced at low values of e^1 (i.e. $e^1 < 100$ kPa). The values of mr^1 and cr^1 (effective residual cohesion) quoted in this report are derived from the best linear fit on the 'shear stress v normal stress' plot, and are probably unreliable at low values of e1. The strength along relic natural shear planes was not investigated in the laboratory, but where present the 'field' strength along these discontinuities would be expected to be approaching residual values.

Fig. 6 shows the relationship between effective residual friction angle (mr1) and Plasticity Index (P.I.), and Fig. 7 shows the plot of effective residual friction angle v %Clay content. Although there are insufficient points to define satisfactory envelopes, a trend towards a decrease in mr1 with increases in P.I. and %Clay content is seen (see also Skempton,1964; Cripps & Taylor, 1981; Lupini et al, 1981).

4.1.2. Melange

A total of 6 samples of Kathikas melange from SW Cyprus 'external' to the Phiti/Statos study areas were analysed in the laboratory, three of which were tested for geotechnical index properties (E38,E39, and E80). A sample of 'melange' (E110) from the Pendakomo was also tested. This latter sample (equivalent to the "small olistolith melange" of Swarbrick & Naylor, 1980) was obtained from a distinctive deposit overlying the typical Moni Formation melange, and is thought to represent the S Cyprus counterpart of the Kathikas melange developed above the Mamonia Complex in the Paphos region.

The Atterberg Limits fall well within the range of results obtained for melange from the Phiti-Statos study areas. When plotted on the conventional plasticity chart (Fig. 8), the 'external' melange samples from SW Cyprus fall slightly above the A-line in a manner characteristic of inorganic clays of 'intermediate' to 'high plasticity'. Sample E110, from S Cyprus, plots within the range of 'very high plasticity' clays.

Areal variation in geotechnical index properties of the Kathikas Melange appears to be small, i.e. little difference appears to exist between the geotechnical properties of the

FIG. 6

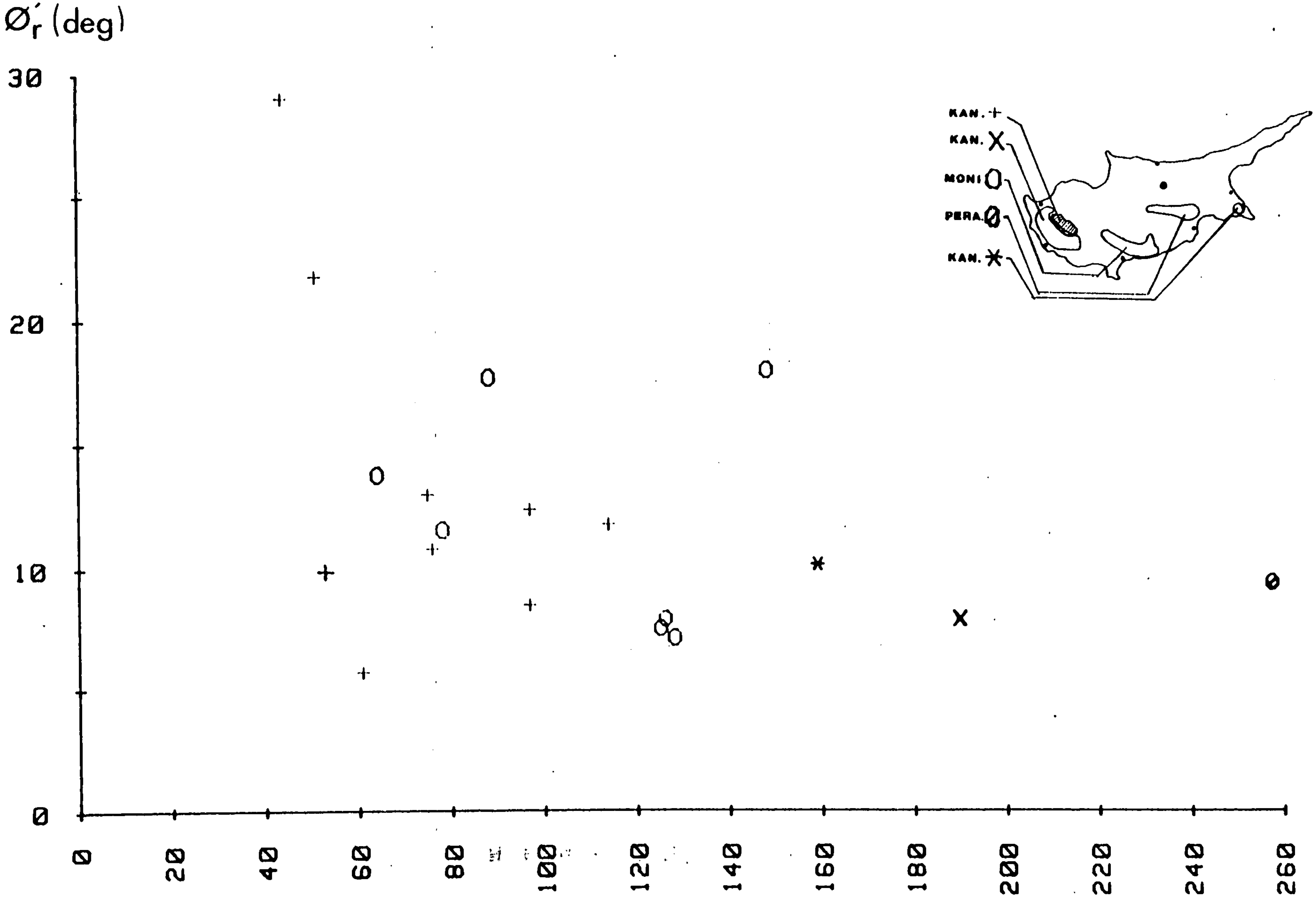


Fig. 6 Residual friction angle v Plasticity index - Kannaviou, Moni & Perapedhi formations

FIG.7

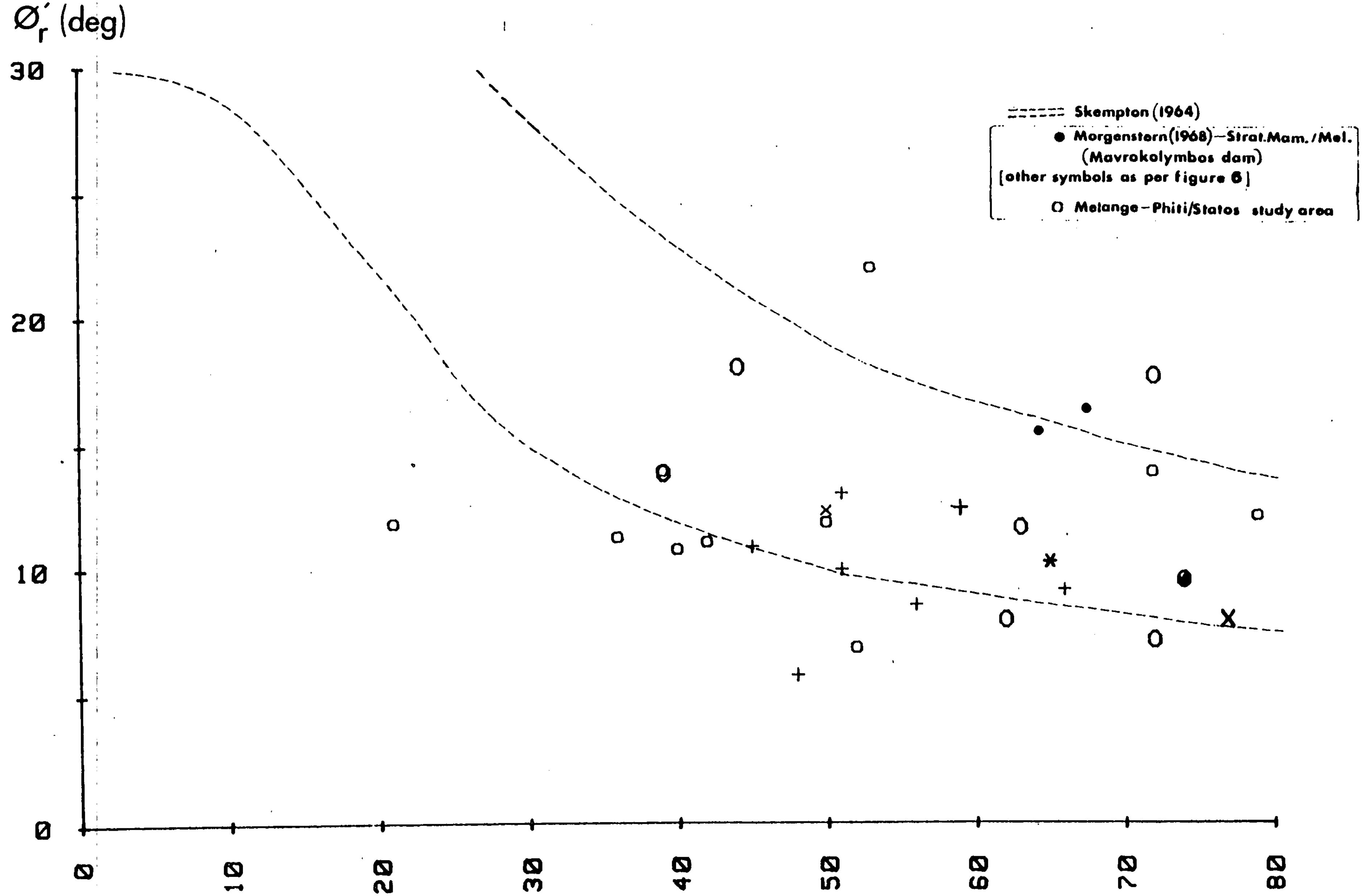


Fig. 7 Residual friction angle v clay fraction – Kannaviou, Moni, Perapedhi & Melange formations

FIG.8

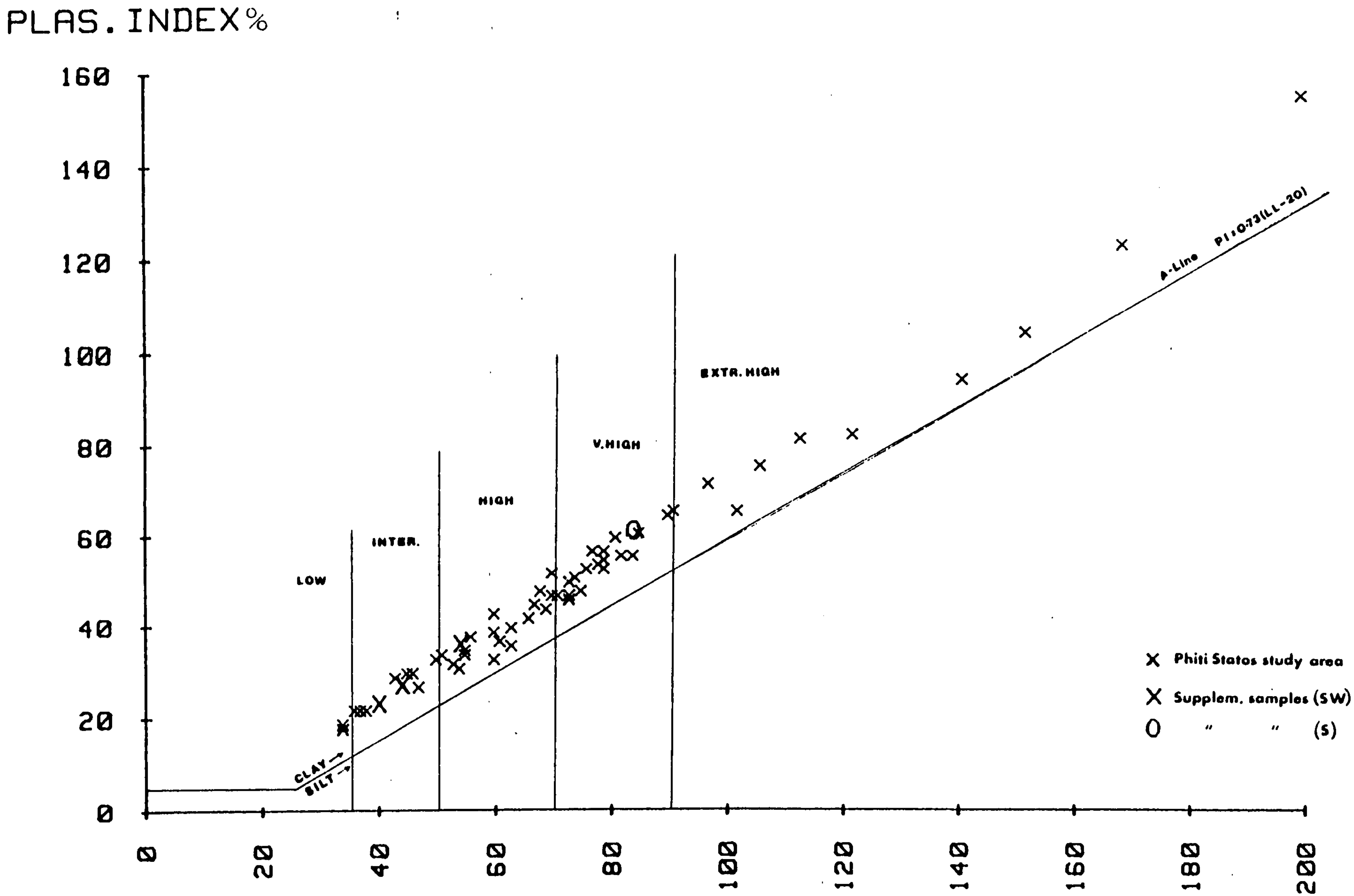


Fig. 8 Casagrande plasticity plot - Melange

Kathikas melange in the Phiti-Statos and Kathikas-Arodhes areas of SW Cyprus. Mass engineering behaviour is, however, likely to be influenced by variations in clast content and the presence of shear zones related to 'recent' landslipping. Too few examples of the equivalent melange in the Pendakomo - Moni area of S Cyprus have been examined for a valid statistical comparison to be made with the Kathikas melange of SW Cyprus. However, the limited results obtained indicate that the former may be more plastic and have higher montmorillonite contents than the latter, as a result of natural mixing with the underlying Kannaviou bentonitic clays of the Moni Formation.

A major engineering project involving 'melange' deposits at the site of the Mavrokolymbos dam in SW Cyprus, produced some geotechnical index data (Morgenstern & Kennard, 1968). It seems likely, however, that these data refer to highly weathered and disturbed stratified Mamonia or 'superficial melange' rather than the Kathikas melange proper.

4.1.3. Stratified Mamonia Rocks (including weathered stratified Mamonia deposits and 'superficial melange')

Geotechnical and mineralogical characterization of the variable suite of rock formations which comprise the sedimentary (stratified) Mamonia Complex was beyond the scope of the current study. Emphasis in both sampling and testing was, therefore, placed on obtaining regional data pertaining to the dominant weathering products of these rocks in SW Cyprus. These weathered and/or broken and sheared materials consist predominantly of red silty clays and red shaley mudstones (or 'clay shales') derived mainly from the shale and chert units of the Mamonia Complex, and grey silty clays derived from other Mamonia sandstone/shale formations which are not differentiated here.

Twelve samples were tested for geotechnical index properties, 9 of which were red shaley clays with grey silty clays comprising only 3 samples. All were obtained from regional sampling sites in SW Cyprus 'external' to the Phiti-Statos study area.

When plotted on the conventional plasticity chart (Fig. 9), all samples fell within the range indicative of inorganic clays of 'intermediate' to 'high plasticity'. No marked differences in plasticity characteristics were found between the red and grey clays. Sample E44 from Ayia Marinoudha (not shown on Fig. 9) recorded a liquid limit value of 83% and thus lies in the 'very high' plasticity range. This sample was considered untypical as it represents highly remoulded, and probably contaminated, landslip debris. The plasticity ranges shown in Fig. 9 are similar to those recorded for similar weathered Mamonia samples from the Phiti-Statos area and, also, fall well within the lower to middle range of the Kathikas melange samples of SW Cyprus (Fig. 8). The similarity between weathered stratified Mamonia index properties to those of the melange is to be expected, since both materials are derived from the same source rocks. The weathered deposits may, in fact, be considered to represent an immature or superficial melange which has not under gone break-up and mixing to the same extent as the melange 'proper'.

Ring shear tests were carried out on three samples to determine residual strength parameters, i.e. samples E68 (Episkopi), E76 (Mavrokolymbos) and E93 (Dhiarizos). Samples E68 and E93 behaved similarly with C^{1}_{r} and m^{1}_{r} values of 15.0 kPa, 10.0^{o} and 15.3 KpA, 14.0^{o}, respectively; whilst sample E76 recorded C^{1}_{r} and m^{1}_{r} values of 6.2kPa and 25.6^{o}, showing a much more frictional, less cohesive behaviour, possibly due in part to its lower montmorillonite content.

Rapid and often marked changes in Mamonia bedrock lithologies, degree of weathering and/or disturbance by surface movement, and tectonic disruption will give rise to local variations in both thickness of the overlying weathered deposits and their geotechnical and mineralogical properties. The red and grey clay shale sequences of the stratified Mamonia rocks appear particularly prone to weathering and breakdown.

FIG.9

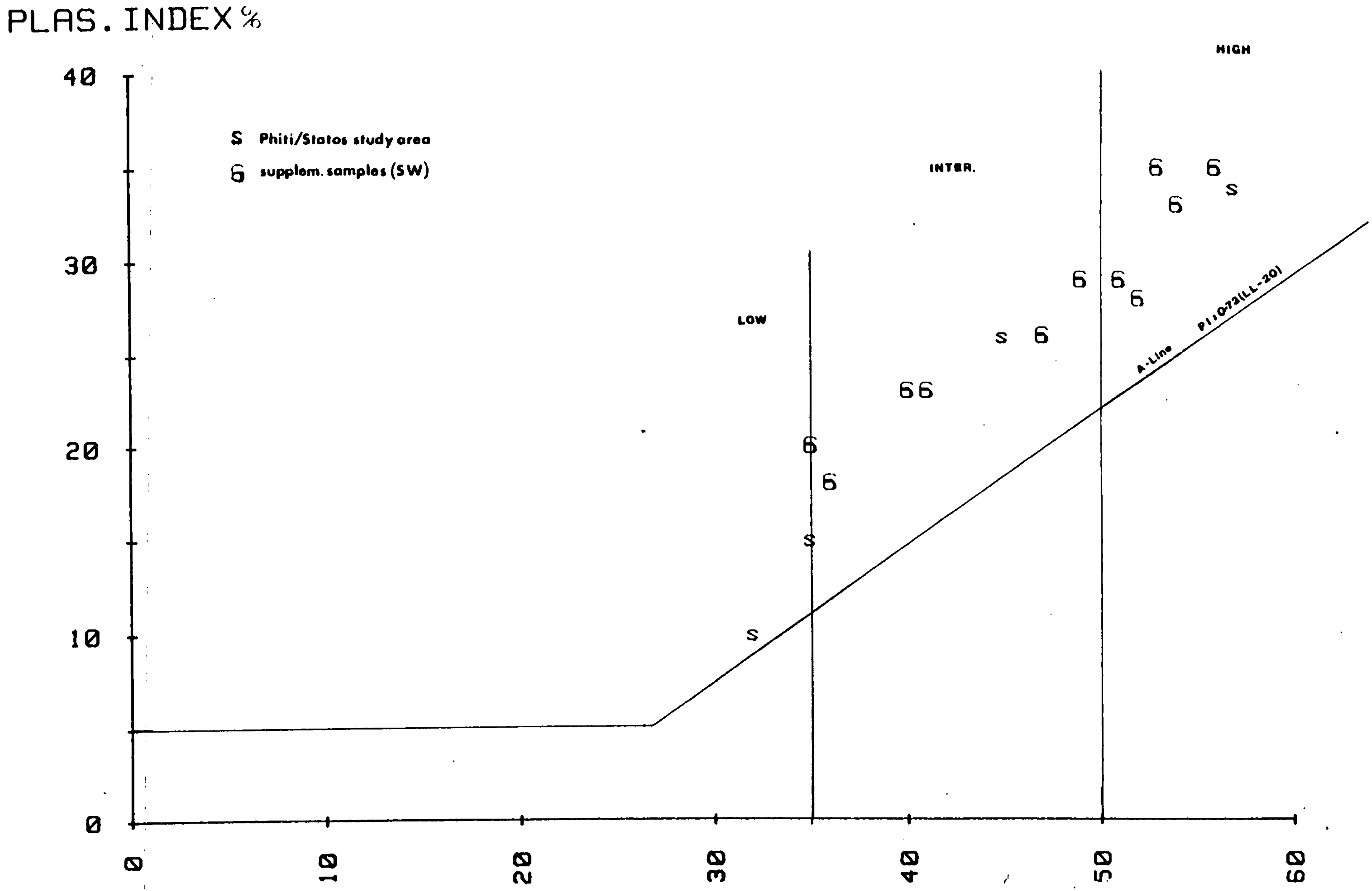


Fig. 9 Casagrande plasticity plot - stratified Mamonia

This is borne out by the limited laboratory tests carried out on these materials which indicate significant montmorillonite contents, a marked loss of strength on remoulding/wetting, and a tendency to break up into gravel-size angular peds on drying. The red clay shales in particular constitute a significant proportion of the stratified Mamonia formation at outcrop, and their role as the dominant source rocks of the Kathikas Melange clay matrix and colluvial slope deposits (e.g 'superficial melange') in SW Cyprus is in little doubt.

4.1.4 Marl

Twenty-six supplementary marl samples were tested for geotechnical index properties and 29 for mineralogical analyses (sample locations across Cyprus are shown on Fig. 2).

The mean values of liquid limit and plasticity index, determined statistically for all regional marl samples except those from the Polis area which are described elsewhere (Rep. No. EGARP KW/86/3, this series), are 66.6% (SD=21%, n=19)[1] and 38.8% (SD=15.5%, n=19), respectively.

The Casagrande plasticity plot (Fig. 10) shows that virtually all the marls fall within the range characteristic of 'intermediate' to 'very high plasticity' clays. The plasticity chart also shows that the Nicosia marls of central Cyprus are of generally higher plasticity than Pliocene marls from the Polis area or elsewhere. Two regional samples (E52 and E54) from SW Cyprus did, however, record plasticity values indicative of extremely plastic clays. The samples, of Upper Miocene Pakhna marl, were obtained from thin interbeds within a marly chalk sequence exposed in road cuttings near the villages of Tsadha and Stroumbi. Sample E52 is unusual in that it has a very high liquid limit (135%), no detectable montmorillonite content, and a carbonate content of 78%. Sample E54 has a liquid limit of 97% with a montmorillonite content of 36%.

[1] SD = Standard Deviation; n = number of observations (data values)

FIG. 10

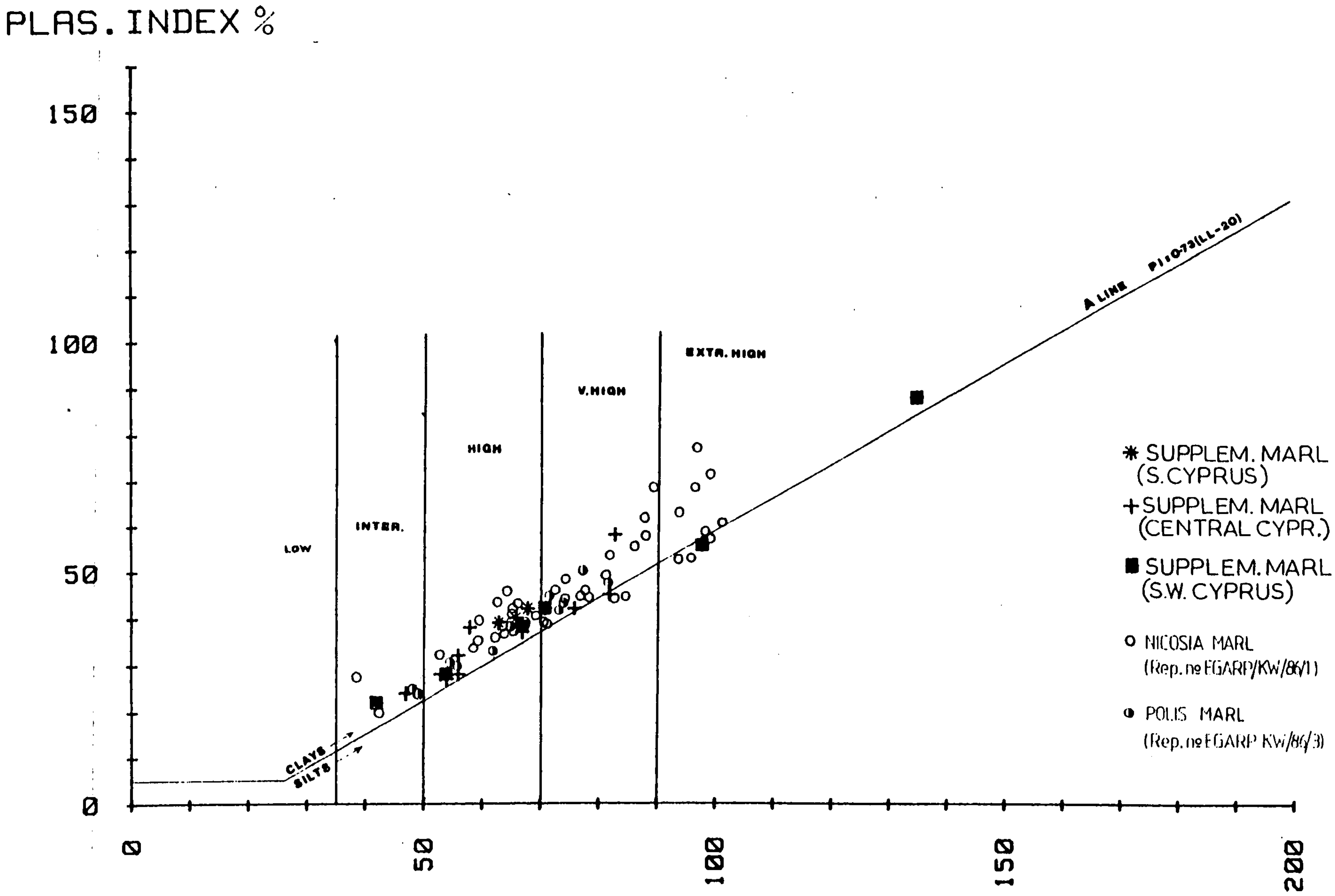


Fig. 10 Casagrande plasticity plot - marls

Insufficient samples of Pakhna marl were collected to ascertain if these high plasticities are characteristic, however, it is clear that where these interbeds are present, excavation of open cuts in the Pakhna chalk formation should be treated with caution, as unfavourable (into-cut) bedding dips are likely to cause pronounced stability problems.

Statistical analysis of particle size results for the supplementary marl samples (excluding those from the Polis area) show that the mean clay content, %Clay, is 28.1% (SD=10.7%, n=19). Values of Activity (Ac = PI/ %Clay) record a statistical mean of 1.5 (SD=0.6%, n=19), i.e. the marls fall into the category of 'active' clays (Skempton,1953).

Particle size and mineralogical classifications of the marls obtained from various localities in Cyprus are shown as two triangular plots in Fig. 11. The 'sand/silt/clay' and 'carbonate/montmorillonite/other' plots, Fig. 11a and 11b, respectively, distinguish the supplementary marls from those of the Polis and Nicosia areas. The plots clearly highlight the wide lithological variation within all the marls except for those found in the Nicosia area of central Cyprus, which appear to be relatively homogeneous. The triangular plot of Fig. 11b, devised for the classification of Pliocene marls in the Nicosia study area (Rep. No. EGARP KW/86/1), shows that with the the exception of the Nicosia marls, the majority of marls sampled from elsewhere in Cyprus fall largely within the 'sandy marl' and 'marly calcarenite' groupings.

Petrides & Charalambous (1981) describe geotechnical test data for Pliocene marls from Yeronisos Island (to the NW of Paphos). These did not exhibit the high Activity seen in some of the marls from Nicosia and were also somewhat stiffer. Consolidation test results pointed to 'light' overconsolidation (or 'quasi'-overconsolidation) for the Yeronisos samples, possibly due to cementing or desiccation (see also Rep.No EGARP KW/86/1). Care must be taken, however, when comparing sample test data obtained from surveys in different areas and with different ultimate aims, particularly with respect to

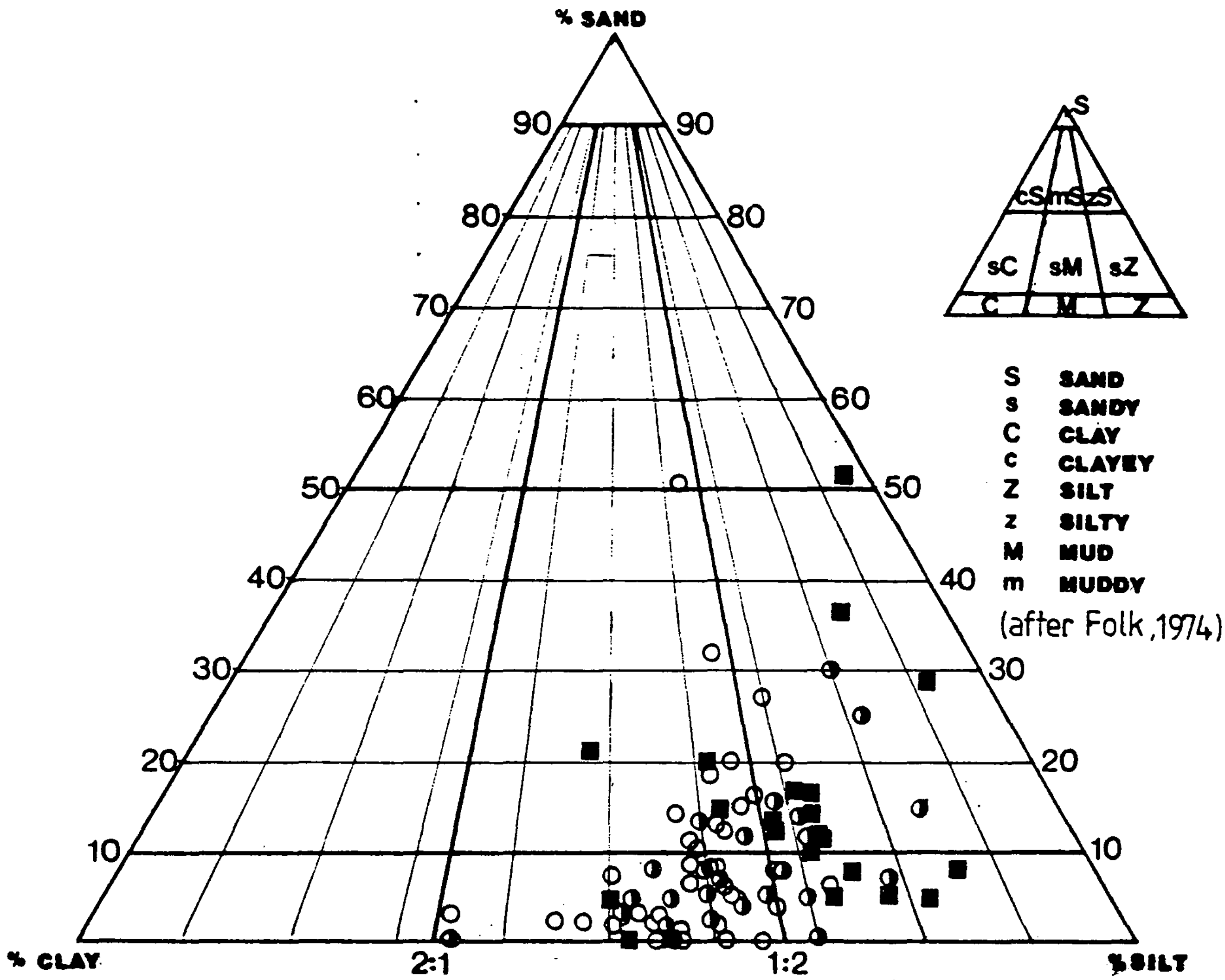
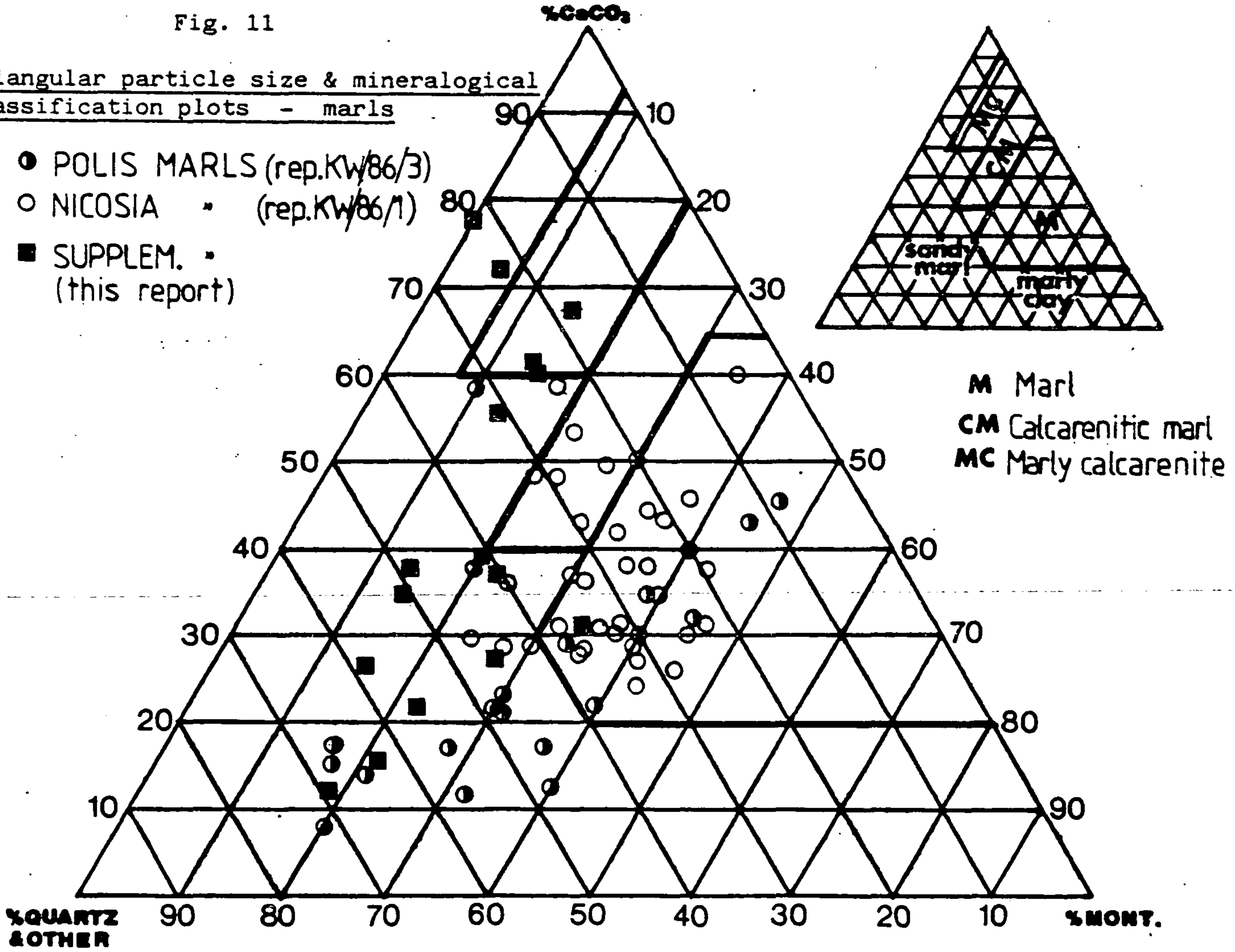


Fig. 11

Triangular particle size & mineralogical classification plots - marls



'representative' sample collection and testing.

4.2 Mineralogical test results

Detailed interpretation of the mineralogical test results with regards to the genesis of the collected materials was beyond the remit of the current study and is not discussed here. General details of mineralogical composition of the main cohesive soil formations are described below, and the test results listed in the Appendix as a factual record.

4.2.1. Kannaviou, Moni and Perapedhi Formations

The statistical mean values of carbonate content and montmorillonite content for supplementary Kannaviou clay/mudstone samples from S.W. Cyprus, outside the Phiti/Statos study area, are 4% (SD = 3.2%) and 51% (SD = 9.1%), respectively. The total number of Kannaviou samples tested was 17. The mean values of carbonate content and montmorillonite content for Moni clay (S. Cyprus) are 9% (SD = 13.2%) and 51% (SD = 8.7%) respectively. The total number of Moni samples tested was 13. As can be seen the 'supplementary' Kannaviou results are very close to those of the Moni clays, with montmorillonite contents generally higher than clays from the Kannaviou Formation in the Phiti-Statos study area. However, fewer samples were tested than would have been ideal for statistical purposes and the results may be influenced by the selection of limited representative regional supplementary samples.

A plot of montmorillonite content v plasticity index for the supplementary bentonitic clay samples is shown in Fig. 5, where the results are compared to data obtained for Kannaviou clay/mudstone samples from the main Phiti-Statos study area in SW Cyprus.

4.2.2 Melange

A total of seven melange samples were tested for mineralogical content. Samples E16 (Nata) and E110 (Moni) show montmorillonite contents higher than the 22% mean for the Phiti/Statos study area samples, whereas the remainder are slightly lower. A particularly high carbonate content of c.22% was obtained for sample E110 from the Pendakomo area of S Cyprus, however, it is likely that this sample has been naturally intermixed with overlying chalk debris. Quartz contents for samples E63 (Kholetria), E80 (Kathikas) and E82 (Arodhes) are generally higher than the Phiti/Statos mean of 17.7%.

Local, relatively minor, variations in mineralogical composition of the Kathikas melange, as with geotechnical index properties, are likely to be related to the dominant source rocks of the Mamonia Complex from which this deposit is derived.

X-ray diffraction analyses reported by Swarbrick and Naylor (1980) show distinct peaks for haematite and goethite. These are not however seen in x-ray diffraction data reported here (see Report EGARP KW/86/4).

4.2.3. Stratified Mamonia Rocks (including weathered stratified Mamonia deposits and 'superficial melange')

Nineteen samples of stratified Mamonia were tested for mineralogy. These consist mainly of red and grey shales and clays all collected from the Polis/Paphos area (S.W. Cyprus) with the exception of sample E98 (Akrotiri). Sample E106 (Pyrgos, E. of Limassol) is from a bentonitic clay band within the Akamas sandstone member of the stratified Mamonia group and has an unusually high montmorillonite content of 60%.

Agreement between GSD data and BGS data (tabulated in the Appendix) is not particularly good. This is probably due to the fact that the mineralogy of the stratified Mamonia shales and clays varies rapidly from one lamination or horizon to the next and hence from one sub-sample to another. This throws some doubt on the reliability of data from these materials in assessing regional variations. Clearly, care is needed to pick sub-samples from exactly the same horizon.

Samples E83, E88 and E37 come under the heading 'superficial melange'. The 'superficial melange' is derived by breaking up, weathering, and possibly limited downslope movement of the in-situ stratified Mamonia which results in a random broken structure having a distinct fine-grained 'matrix' component which is distinct from a coarse-grained, blocky 'clast' component (for full discussion refer to Report No. EGARP KW/86/4, this series). Much less variation in the BGS and GSD mineralogical data was obtained for this weathered colluvial material as a result of the weathering and 'mixing' of the variable underlying Mamonia lithologies.

In brief, the mineralogical compositions of the supplementary ('external') samples were similar to those obtained within the Phiti-Statos study area. Where detected, montmorillonite contents (ranging from 14 - 32%) were similar to those recorded in the Kathikas melange samples of SW Cyprus.

4.2.4 Marl

Mineralogical analyses were carried out on 23 supplementary marl samples from regional sites in S, SW, and central Cyprus (Fig. 2). An additional 6 samples of marl from the Polis area of W Cyprus were also tested and these results are discussed fully in Report No. EGARP KW/86/3. The majority of samples consisted of Pliocene marls from the Nicosia Formation; 4 samples were obtained from the Middle Miocene Pakhna Formation (E24, E52, E54 and E113); and 1 sample from the Upper Maestrichtian to Oligocene Lefkara Formation (E114). The mineralogical results are shown in the form of a triangular $CaCO_3$/Montmorillonite/Other plot in Fig. 11 (see discussion in section 4.1.4, above).

Statistical analysis of the test results (excluding those for marls from the detailed Nicosia and Polis study areas) shows the mean carbonate content to be 38% (SD = 19, n = 23) and the mean montmorillonite content to be 16% (SD = 8, n =

16). This compares with a mean carbonate content of 36% (SD=10.7) and a mean montmorillonite content of 19% (SD=5.2) for the marls of the Nicosia area (see Rep.No EGARP KW/86/1). Sample E3 (Kalavasos) exhibits large discrepancies between the GSD and the BGS results in some cases, probably due to lithological differences in the respective sub-samples. Common trace minerals found in the marls include quartz, felspar, chlorite, mica, amphibolite and dolomite. Samples E18 and E30 from Pissouri contain gypsum. Samples E24 (Ay. Phyla) and E113 (Halassa) contain aragonite (orthorhombic $CaCO_3$). Sample E112 (Mari) contains Amphibolite and sample E3 contains clinoptilolite.

5. <u>CONCLUSIONS</u>

Geological and geotechnical assessments of a wide variety of cohesive soils associated with the Troodos Ophiolite complex have been made in the 'cohesive soils study'. In this report, comparisons have been drawn between the regional 'supplementary' samples obtained from selected sites across Cyprus and those samples from the same formations described in the detailed 'study area' reports. Whilst these comparisons are necessary in order to assess regional variations in geotechnical properties, it must be appreciated that care should be taken when extrapolating geotechnical data between different sampling/study locations for two reasons:

Firstly, lithological and geotechnical differences may exist which have not been recognised or tested for, and secondly, the initial choice of representative field samples for projects with different ultimate aims may lead to certain lithological biases, which are reflected in the geotechnical test results.

If comparisons are drawn, for example, between test data obtained for marl samples from supplementary regional sites across Cyprus and the data from the Nicosia study area, it should be borne in mind that in the latter case, undisturbed samples from boreholes were used and a more detailed geotechnical test programme undertaken. Thus, whilst it may be valid to estimate a parameter such as swelling pressure from plasticity indices determined on disturbed bulk regional samples, it may be inappropriate to extrapolate actual values measured on similar, but undisturbed, samples from the Nicosia study area.

It has been shown that broad classifications can be made on a regional basis using geotechnical 'index' test results (e.g. liquid and plastic limits and plasticity indices) and simple mineralogical test results such as montmorillonite and carbonate contents. Grouping of data points for the marls, for example, can be seen in Fig. 11. Here, the scatter of the 'supplementary' regional data relative to data obtained for marl in the Polis and Nicosia study area investigations, indicates that a greater lithological variation appears to occur in marl deposits from areas other than those around Nicosia in central Cyprus. In the case of the bentonitic clays of the Kannaviou, Moni and Perapedhi Formations, the majority of samples occupy common locations on the various geotechnical and mineralogical plots; the exceptions being two extremely plastic clays (liquid limit >220%) from opposite ends of the island (see Fig. 3). Correlation between plasticity index and montmorillonite content for the bentonitic clays (see Fig. 5) is generally good, and it would appear that the montmorillonite content is a major determining factor in the engineering behaviour of these materials. The behaviour of the marls is probably a function of both montmorillonite and carbonate contents.

An unusual plot of plastic limit v log plasticity index is given in Fig. 12. This plot shows the regional data groupings more clearly than the standard Casagrande plasticity chart; data for Kannaviou and Melange clays from the Phiti/Statos study areas are superposed for comparison.

Important factors when considering the engineering behaviour of the bentonitic clays of the Kannaviou, Moni and

FIG.12

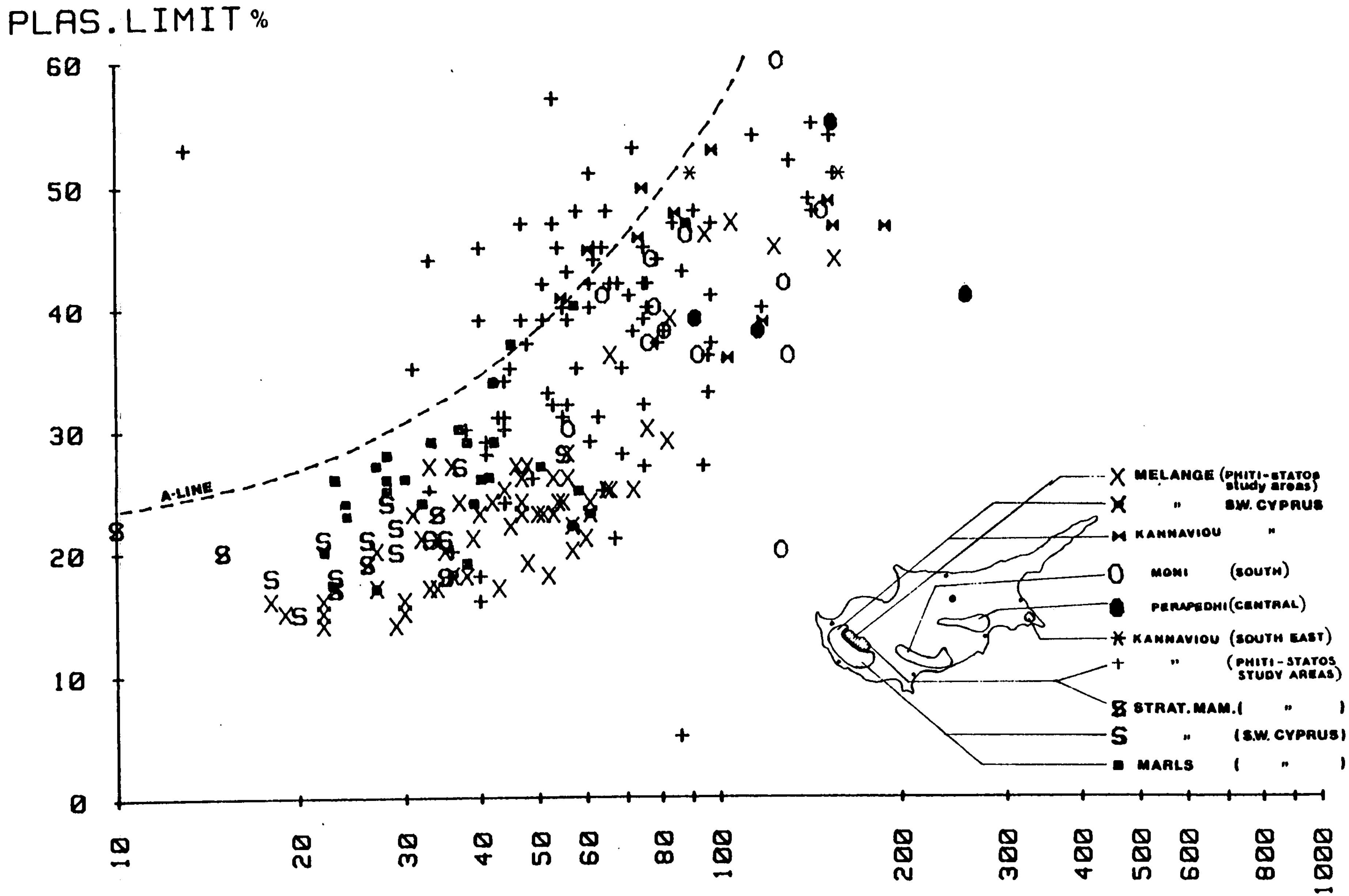


Fig. 12 Plastic limit v (log) Plasticity index - Kannaviou, Melange, stratified Mamonia, Moni & Perapedhi clays, marls

Perapedhi Formations are the presence or absence of a sheared fabric, and the presence or absence of sandstone or siltstone bands within the formation. The characteristic "scaley" or "pervasively sheared" fabric, described in reports EGARP KW/86/2 and EGARP KW/86/4, has a profound influence on the 'field' behaviour of these materials when subjected to loading or unloading. No 'undisturbed' samples were obtained during the regional supplementary sampling and strength parameters could not, therefore, be directly determined. The 'field' strength of these sheared clays is, in any case, extremely difficult to measure in the laboratory but probably approaches minimum (residual) values; in addition, the strength loss from peak to residual is particularly great for clays of high plasticity. The origins of the stresses which have resulted in apparently random shears or fissures in these deposits are probably multifarious, involving one or more processes associated with tectonic, earthquake, stress relief, physicochemical and gravitational forces.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. K. Solomi (GSD) and Mr. D. Entwisle (BGS) for carrying out the laboratory testing of soil samples; and Ms Sarah Vaughan (University College, London) for making a number of her samples available for geotechnical and mineralogical analysis. The authors are particular grateful to Mr. G. Petrides and Dr. G. Constantinou (director) of GSD for their active involvement and encouragement throughout the project.

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APPENDIX

SAMPLE LISTING AND SUMMARY OF GEOTECHNICAL AND MINERALOGICAL TEST RESULTS

CYPRUS TEST DATA

SAMPLE LISTING and INDEX TEST RESULTS

for

'External' Samples

(ie. samples obtained from outside main study areas at selected sites across Cyprus)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
	E 1	S	chalky marly cl	52990/388040	D				64	27	37				-	2	61	37	1.00
	E 2	S	chalky marly cl	53650/387750	D														
	E 3	S	chalky marly cl	52850/384530	D				128	44	84				-	2	63	35	2.40
	E 4	S	MONI bentonitic cl	51140/384540	D				105	41	64				1	10	50	39	1.64
	E 5	S	MONI bentonitic cl	52110/384370	D														
	E 6	S	MONI bentonitic cl	52320/384280	D														
	E 7	S	KAN cl	55240/387590	D														
	E 8	S	KAN cl	"	D				130	39	91				-	1	22	77	1.18
	E 9	S	KAN cl	55450/387720	D														
	E 10	S	KAN cl	"	D														
	E 11	S	KAN cl	"	D				298	41	257				-	1	25	74	3.47
	E 12	S	KAN cl	58850/387650	D				210	51	159				-	4	31	65	2.44
	E 13	S	KAN cl	45870/386450	D														
	E 14	S	MEL matrix	"	D														
	E 15	S	KAN cl	46360/386420	D														
	E 16	S	MEL matrix	46070/384900	D														
	E 17	S	KAN cl	46120/386870	D				237	47	190				-	1	22	77	2.46
	E 18	S	silty marl	47500/383750	D				67	29	38				-	8	79	13	2.92
	E 19	S	ALLUVIUM	46010/386160	D														
	E 20	S	bentonitic cl	52580/385130	D				134	46	88				-	2	26	72	1.22
	E 21	S	bentonitic cl + gypsum	52520/385360	D				196	48	148				-	6	50	44	3.36
	E 22	S	TOPSOIL	50300/385640	D														
	E 23	S	brick soil	50300/385600	D														
	E 24	S	PAKHNA marl	50030/384540	D				53	25	28				-	11	64	25	1.12
	E 25	S	ALLUVIUM	9220/383570	D														
	E 26	S	marl		D				68	26	42				2	21	37	40	1.05
	E 27	S	bentonitic cl + shl	52230/387370	D														
	E 28	S	PLIOCENE marl	"	D				56	28	28				-	6	73	21	1.33
	E 29	S	cl iron rich		D														
	E 30	S	PLIOCENE marl	47570/383760	D				76	34	42				-	5	78	17	2.47
	E 31	S	PLIOCENE marl	53660/387750	D				56	24	32				-	10	64	26	1.23
	E 32	S	PLIOCENE marl	"	D				47	23	24				-	14	62	24	1.00
	E 33	S	PLIOCENE marl	52690/384380	D				66	26	40				-	13	59	28	1.43
	E 34	S	PLIOCENE marl	"	D				63	24	39				-	12	60	28	1.39
	E 35	S	PLIOCENE marl	51780/387900	D				67	30	37				-	8	69	23	1.61
	E 36	S	PLIOCENE marl	"	D				53	25	28				-	7	66	27	1.04
	E 37	S	ST.MAM. superficial	46000/384800	D				47	21	26							35	0.74
	E 38	S	MEL matrix	46000/385900	D				40	17	23							30	0.77
	E 39	S	MEL matrix	45870/386420	D				44	17	27							30	0.90
	E 40	S	PLIOCENE marl	44900/387420	D				56	26	30				-	29	65	6	5.00
	E 41	S	PLIOCENE marl	44880/387590	D				62	29	33				-	12	63	25	1.32
	E 42	S	MAM.sh'd,weath'd lava	44630/386990	D				52	24	28				-	69	23	8	3.50
	E 43	S	ST.MAM. red clay/shale	44550/385810	D				41	18	23				-	48	27	25	0.92
	E 44	S	ST.MAM. red clay	45360/384650	D				83	28	55				-	6	59	35	1.57
	E 45	S	KAN clay	50250/385100	D				107	30	77				-	-	42	58	0.75
	E 46	S	KAN clay	"	D				103	45	57				-	-	35	65	0.88
	E 47	S	PLIOCENE marl	45135/387070	D				77	27	50				-	9	53	38	1.31
	E 48	S	PLIOCENE marl(Polis)	45135/386450	D														

SAMPLE LISTING and INDEX TEST RESULTS (cont'd)

?/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
	E 49	S	PLIOCENE marl(Polis)	45175/386450	D				82	37	45				-	-	70	30	1.50
	E 50	S	PLIOCENE marl(Polis)	45160/386835	D				48	24	24				-	12	64	24	1.00
	E 51	S	PLIOCENE marl(Polis)	44900/38730	D				49	26	23				-	15	71	14	1.64
	E 52	S	PAKHNA marl	45160/385535	D				135	47	88				-	-	52	48	1.83
	E 53	S	PLIOCENE marl	45065/385385	D				42	20	22				-	14	53	33	0.66
	E 54	S	PAKHNA marl	45250/386120	D				97	40	57				-	6	68	26	2.19
	E 55	S	KAN cl	45440/387170	D				120	46	74				-	-	40	60	1.23
	E 56	S	KAN cl	45310/387175	D				158	39	119				-	-	16	84	1.41
	E 57	S	KAN mdst	45240/385030	D				96	41	55				-	6	49	45	1.22
	E 58	S	KAN mdst	45220/385060	D				106	45	61				-	50	27	23	2.65
	E 59	S	KAN mdst	45320/385000	D				125	50	75				-	-	42	58	1.29
	E 60	S	KAN mdst	45290/385020	D				133	48	85				-	-	49	51	1.66
	E 61	S	KAN mdst	46385/384815	D														
	E 62	S	ST.MAM. red shale	46225/384615	D														
	E 63	S	MEL matrix	46225/384815	D														
	E 64	S	KAN cl	46110/384830	D														
	E 65	S	KAN cl	46110/384830	D				202	49	153				-	-	22	78	1.96
	E 66	S	KAN cl	45980/384915	D														
	E 67	S	KAN cl	45980/384915	D														
	E 68	S	S.MAM. weathd redsh cl	45950/384925	D														
	E 69	S	S.MAM. weathd,cl+clasts	45940/384925	D				56	21	35				-	34	43	25	1.40
	E 70	S	S.MAM. weathd,clasts+cl	45880/384925	D				53	18	35				-	50	32	18	1.94
	E 71	S	SERPENTINITE,weath'd	45850/364950	D														
	E 72	S	ST.MAM. redsh shales/cl	45850/384950	D										-	71	20	9	
	E 73	S	S.MAM.cl+mudst,grey	45785/385015	D				51	22	29				-	9	60	31	0.93
	E 74	S	KAN cl	45790/385010	D				203	47	156				-	-	21	79	1.97
	E 75	S	SERPENTINITE,weath'd	44645/384905	D														
	E 76	S	STRAT MAM	44610/385778	D														
	E 77	S	ST.MAM. redsh cl,hard	44610/385785	D														
	E 78	S	SERP.weath'd to cl	44610/388578	D														
	E 79	S	MEL matrix	44665/386255	D														
	E 80	S	MEL matrix	44645/386235	D				54	18	36					18	43	39	0.92
	E 81	S	KAN clay/mudst	44675/386610	D				151	53	98				-	2	35	63	1.55
	E 82	S	MEL matrix	44675/386610	D														
	E 83	S	ST.MAM,supfl grey clay	44415/386715	D				36	18	18				-	20	66	14	1.28
	E 84	S	KAN clay,fissured	44300/386550	D				140	36	104				-	-	50	50	2.08
	E 85	S	ST.MAM. red shales+chts	44375/387280	D														
	E 86	S	ST.MAM. red shales/cl	44375/387280	D				49	20	29				-	24	43	33	0.87
	E 87	S	KAN slty clay/mudst	43920/387165	D														
	E 88	S	S.MAM,supfl grey clay	44010/387135	D														
	E 89	S	ST.MAM,red shale	•	D														
	E 90	S	ST.MAM. red shales/cl	46310/384400	D				40	17	23				-	57	27	16	1.43
	E 91	S	ST.MAM. shales/cl	46405/384500	D				54	21	33				-	5	55	40	0.82
	E 92	S	ST.MAM. slty shales	46415/384510	D				35	15	20				-	9	74	17	1.17
	E 93	S	ST.MAM. gry shaley cl	47050/384940	D														
	E 94	S	ST.MAM. redsh shaley cl	47180/385065	D														
	E 95	S	S.MAM. slty shales/cl	46940/384890	D				47	21	26				-	8	47	45	0.57
	E 96	S	PLIOCENE marl	47265/383705	D														
	E 97	S	PLIOCENE marl	444680/38481	D				71	29	42				-	-	56	44	0.95
	E 98	S	ST.MAM, red shale	49425/382532	D														
	E 99	S	PLIOCENE marl	5792/38758	D				-	-	-				-	52	46	2	
	E 100	S	PLIOCENE marl	5576/38690	D				83	25	58				-	4	48	48	1.20
	E 101	S	KAN clay	5898/3876	D				141	51	90				-	1	19	80	1.12

SAMPLE LISTING and INDEX TEST RESULTS (cont'd)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	GRID REFERENCE	TYPE	MC %	BD Mg/m3	DD Mg/m3	LL %	PL %	PI %	LI	LS %	SG	Gr %	Sa %	Si %	Cl %	A
	E 102	S	SERPENTINITE,weath'd	59355/38717	D														
	E 103	S	KAN clay(Perapedhi)	55450/38772	D				154	38	116				-	-	23	77	1.50
	E 104	S	KAN clay(Perapedhi)	55400/38772	D				209	55	154				-	-	21	79	1.95
	E 105	S	MONI clay	5154/3843	D				128	36	92				-	-	23	77	1.19
	E 106	S	ST.MAM.(AKAMAS SST.)	"	D														
	E 107	S	SERPENTINITE	"	D														
	E 108	S	MONI clay	5118/38443	D				121	44	77				-	8	36	56	1.37
	E 109	S	MONI clay	5196/38439	D				166	36	130				-	4	26	70	1.85
	E 110	S	MEL (Moni area)	5206/38438	D				84	23	61				-	39	38	33	1.84
	E 111	S	MONI clay	5108/38458	D				119	38	81				-	3	24	73	1.10
	E 112	S	MONI marl	5282/38452	D				54	27	27				-	37	53	10	2.70
	E 113	S	PAKHNA marl	49305/384595	D				54	26	28				2	17	59	22	1.27
	E 114	S	L.LEFKARA marl	4924/385425	D				58	19	38				-	20	49	31	1.22
	E 115	S	KAN clay(Perapedhi)	4892/38576	D				56	30	56				-	18	34	46	1.16
	E 116	S	KAN clay(Perapedhi)	"	D				113	37	76				-	15	35	50	1.52
	10/82	2.85	MONI clay (Pendakomo)	5220/38430	U				185	60	125				-	-	10	90	1.39
	10/82	4.25	MONI clay (Pendakomo)	"	U	39			170	42	128	-0.02			-	3	25	72	1.78
	10/82	8.25	MONI clay (Pendakomo)	"	U	19			146	20	126	-0.01			-	-	38	62	2.03
	10/82	10.25	MONI clay (Pendakomo)	"	U	25			118	40	78	-0.19			-	-	37	63	1.24
	11/82	2.25	MONI clay (Pendakomo)	"	U	38													
	11/82	8.25	MONI clay (Pendakomo)	"	U	33													

CYPRUS TEST DATA

LABORATORY STRENGTH TEST RESULTS

(CU Triaxial Tests and Ring-shear Tests)

for

'External' Samples

(ie. samples obtained from outside main study areas at selected sites across Cyprus)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	Cu kPa	Øu Deg	C' kPa	Ø' Deg	Ør' Deg (σ_n'=) (σ_n'= 76kPa)	(σ_n'= 150kPa)	(σ_n'= 248kPa)	(σ_n'= 497kPa)	Best Linear Envelope Cr' kPa	Ør' Deg
	E3	S	Marly clay(Kalavasos)					32.8	32.7	32.7	32.9	0.0	32.8
	E4	S	MONI bentonitic cl					21.3	18.9	17.2	15.0	12.0	13.8
	E11	S	Bentonitic clay(Kellia)					15.5	13.0	11.8	10.5	9.2	9.5
	E12	S	KAN clay(Paralimni)					14.7	12.9	11.5	10.8	6.6	10.2
	E17	S	KAN cl					13.6	11.5	9.5	8.9	8.5	7.9
	E18	S	Sandy marl(Pissuri)					32.9	31.3	29.9	29.8	6.4	29.2
	E20	S	Bentonitic cl (Dhrapia)					24.0	22.3	20.5	18.9	11.8	17.7
	E21	S	Bentonitic cl (Parsata)					24.2	22.0	20.9	19.1	11.6	18.0
	E24	S	PAKHNA marl					32.7	31.8	31.7	31.4	0.6	31.8
	E27	S	Bent.cl/shale(Kambia)					31.5	29.7	28.9	28.6	5.6	28.1
	E68	S	ST.MAM,red shaly clay					19.6	16.0	13.6	11.6	15.0	10.0
	E76	S	ST.MAM,red shaly clay					29.5	27.3	27.0	26.3	6.2	25.6
	E93	S	ST.MAM, grey shaly clay					21.7	19.2	16.3	15.3	12.4	14.0

CYPRUS TEST DATA

MINERALOGICAL RESULTS

for

'External' Samples

(ie. samples obtained from outside main study areas at selected sites across Cyprus)

Marl

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	(GSD) CaCO3 %	(Meth. Blue) MONT. %	(Thmo. grav.) CaCO3 %	(EGME-sam.) MONT. %	(XRD) QTZ. %	Mineralogical Comp'sn. (XRD)
Xeri	E1	S	PLIOCENE marl	30.0	21.2	27	27	2	Calc/qz/fsp/mont/chl/mica
Dahli	E2	S	PLIOCENE marl			16	21	3	Fsp/qz/calc/amph/mont/chl/mica
Kalavasos	E3	S	Marly clay	3.7	47.5	27	14	2	Fsp/calc/qz/amph/mont/chl/clin
Pissuri	E18	S	PLIOCENE marl	35.0	15.5	22	22	Tr	Calc/fsp/mont/chl/qz/gypsum
Ay.Phyla	E24	S	PAKHNA marl	65.0	14.5	61	14	1	Calc/qz/mont/mica/aragonite
Ay.Ioannis	E28	S	PLIOCENE marl	16.2	18.7	12	19	5	Fsp/qz/calc/amph/mont/chl
Pissuri	E30	S	PLIOCENE marl	28.7					Calc/mont/qz/gypsum/fsp
Dahli	E31	S	PLIOCENE marl	20.0					Qz/fsp/calc/chl/mont
"	E32	S	PLIOCENE marl	20.0					Qz/fsp/calc/chl/mont
Mari	E33	S	PLIOCENE marl	41.2					Calc/qz/fsp/chl/mont
"	E34	S	PLIOCENE marl	41.2					Calc/chl/mont/qz/fsp/mica
Aredhiou	E35	S	PLIOCENE marl	20.0					Mont/calc/chl/fsp/qz
"	E36	S	PLIOCENE marl	22.5					Mont/calc/fsp/chl/qz
Polis	E40	S	PLIOCENE marl	43.7					Mont/calc/gypsum/chl/qz/fsp/h
Polis	E41	S	PLIOCENE marl	8.7					Mont/chl/fsp/qz/calc/h
Evretou	E47	S	PLIOCENE marl	38.1	20.0				
Yiolou	E49	S	PLIOCENE marl	21.8	30.0				
Polis	E50	S	PLIOCENE marl	58.7	10.0				
Khrysokhou	E51	S	PLIOCENE marl	17.5	16.2				
Tsadha	E52	S	PAKHNA marl			78	ND	Tr	Calc/qtz
Mesoyi	E53	S	PLIOCENE marl	71.8	6.2				
Stroumbi	E54	S	PAKHNA marl	30.0	31.7	31	36	Tr	Calc/mont/qtz
Pissuri	E96	S	PLIOCENE marl			60	15	7	Calc/qtz/mont/dol
Mousallas	E97	S	PLIOCENE marl	40.0	17.5	39	20	Tr	Calc/mont/chl/mca/qz/dol
Liopetri	E99	S	PLIOCENE marl	33.7	10.0	39	17	12	Calc/fsp/qz/mont/chl/mca/dol
Livadhia	E100	S	PLIOCENE marl	38.1	20.0	36	24	Tr	Calc/fsp/mont/chl/mica/qtz
Mari	E112	S	PLIOCENE marl	23.1	12.5	35	15	Tr	Calc/fsp/mont/chl/mca/qz/amph
Malassa	E113	S	PAKHNA marl	51.8	13.2	59	13	12	Calc/qtz/mont/aragonite
Lania	E114	S	L.LEFKARA marl	68.7	15.0	68	13	Tr	Calc/mont/qtz

Melange

Mata	E16	S	MEL matrix			ND	29	14	Qtz/mont/chl
Galatr.	E38	S	MEL matrix	13.1					Qtz/calc/mont/felsp
Milia	E39	S	MEL matrix	10.0					Chl/mont/qtz/calc/felsp
Kholet.	E63	S	MEL on St.Mam			7	20	26	Qtz/calc/mont/chl/mica
Kathik.	E80	S	MEL matrix	9.3	15.7	10	16	30	Qtz/calc/mont/chl/mica
Arodhes	E82	S	MEL matrix			11	20	26	Qtz/calc/mont/chl/mica
Moni	E110	S	MEL,Moni area	22.5	29.2	20	32	ND	Calc/mont

MINERALOGICAL RESULTS (cont'd)

Stratified Mamonia and Superficial Melange(weathered St.Mam.)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	(GSD) CaCO3 %	(Meth. Blue) MONT. %	(Thao. grav.) CaCO3 %	(EGME-sam.) MONT. %	(IRD) QTZ. %	Mineralogical Comp'sn. (IRD)
Episk.	E69	S	ST.M.gry cl/mds	1.9	15.7	ND	31	27	Qtz/mont/chl/mica
Episk.	E70	S	ST.M.gry cl/mds	2.5	16.7				
Arodhes	E83	S	ST.M.grey cl			Tr	ND	27	Qtz/chl/mica/calc
Akamas	E88	S	ST.M.grey cl(V)			8	ND	24	Qtz/calc/chl/mica/felsp
Dhiariz	E93	S	ST.M.grey cl(H)						
Mavrok.	E43	S	ST.M,red shale	3.7					Qtz/mont/chl
Ay.Mar.	E44	S	ST.M,red cl	6.8					Qtz/mont/gy
Kholet.	E62	S	ST.M,red shale			ND	18	30	Qtz/mont/chl/mica
Episk.	E68	S	ST.M,red shlycl			ND	32	28	Qtz/mont/chl
Episk.	E72	S	ST.M,red shale	2.5	8.0				
Mavrok.	E76	S	ST.M,red shlycl			ND	25	28	Qtz/mont/chl/mica
Mavrok.	E77	S	ST.M,red shd cl			ND	22	29	Qtz/mont/chl/mica
Androlk	E85	S	ST.M,red shale			ND	ND	60	Qtz/mica
Androlk	E86	S	ST.M,red shlycl	3.7	17.5	ND	21	50	Qtz/mont
Dhiariz	E90	S	ST.M,red shale	6.2	10.7	8	ND	30	Qtz/calc/chl/mica/fsp/dol
Dhiariz	E91	S	ST.M,red shlycl	10.2	18.2	9	ND	29	Qtz/calc/chl/mica
Dhiariz	E92	S	ST.M,red shale	7.1	10.0	6	ND	32	Qtz/calc/mica/gy
Dhiariz	E94	S	ST.M,red shlycl			ND	27	18	Qtz/mont/chl
Dhiariz	E95	S	ST.M,red shlycl	10.0	17.5	9	16	26	Qtz/calc/mont/chl/mica
Nata	E37	S	ST.M,supfl	3.7					Mont/qtz/chl/gy/mica
Akrotir	E98	S	ST.M,red shale			ND	14	33	Qtz/mont/mica
Pyrgos	E106	S	ST.M(Akamas Ss)			ND	60	Tr	Mont/qtz
Droush.	E42	S	MAM.sh'd lava	11.8					Mont/felsp/calc/qtz
Episk.	E71	S	SERP.sheared cl			5	23	ND	Felsp/mont/chl/calc
Paphos	E75	S	SERP.weath'd.			ND	ND	ND	Chl/mica/amphibole
Mavrok.	E78	S	SERP.sheared cl			17	12	ND	Calc/mont/chl
Ay.Napa	E102	S	SERP,weath'd			ND	ND	ND	Felsp/attapulgite

Kannaviou

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	(GSD) CaCO3 %	(Meth. Blue) MONT. %	(Thao. grav.) CaCO3 %	(EGME-sam.) MONT. %	(IRD) QTZ. %	Mineralogical Comp'sn. (IRD)
Asproy.	E15	S	KAN clay			Tr	53	Tr	Felsp/mont/qtz/clino
Nata	E17	S	KAN clay	3.7	57.5	ND	58	2	Qtz/mont
Meladh.	E55	S	KAN clay	6.2	45.0	ND	67	Tr	Mont/qtz
Perist.	E56	S	KAN clay	2.5	51.2				
Armou	E57	S	KAN clay/mudst	2.5	38.7				
Armou	E58	S	KAN clay/mudst	5.0	39.2	ND	46	14	Qtz/mont
Marath.	E59	S	KAN clay/mudst	1.8	45.0				
Marath.	E60	S	KAN clay/mudst	3.7	43.7				
Kholet.	E61	S	KAN clay/mudst			ND	60	12	Qtz/mont
Nata	E64	S	KAN clay/mudst			ND	59	12	Qtz/mont
Nata	E65	S	KAN clay/mudst	3.7	58.7				
Nata	E66	S	KAN clay			Tr	63	7	Qtz/mont/clinopt
Episk.	E74	S	Kan clay	3.7	50.0				
Arodh.	E81	S	KAN clay/mudst	3.1	45.0	ND	40	22	Qtz/mont/calc/fsp/attaplg
Arodh	E84	S	KAN clay,fissd	2.5	45.0	ND	54	Tr	Mont/qtz
Akamas	E87	S	KAN slty mds/cl			16	28	14	Ca/fsp/qz/mont/chl/mca/cl
Parali.	E101	S	KAN clay	1.8	50.0	ND	63	6	Qtz/mont
Parali.	E12	S	KAN clay	3.1	40.0	ND	63	10	Qtz/mont

MINERALOGICAL RESULTS (cont'd)

Moni and Perapedhi Clays
(+ miscellaneous bentonitic clay samples)

PIT/BH NO.	SAMPLE NO.	DEPTH m	LITHOLOGY	(GSD) CaCO3 %	(Meth. Blue) MONT. %	(Thm. grav.) CaCO3 %	(ESME-sam.) MONT. %	(XRD) QTZ. %	Mineralogical Comp'sn. (XRD)
Penda-	10/82	2.25	MONI clay			ND	70	16	Qtz/mont
komo	"	4.25	MONI clay			7	56	17	Calc/qtz/mont/dol
"	"	8.25	MONI clay			35	40	4	Calc/qtz/mont/clinopt
"	"	10.25	MONI clay			41	38	Tr	Calc/mont/chl/qtz/clinopt
"	11/82	2.25	MONI clay			ND	51	16	Qtz/mont/felsp
"	"	8.25	MONI clay			5	45	4	Calc/qtz/mont/chl
"	E6	S	MONI clay			ND	61	7	Qtz/mont
Armen.	E4	S	MONI clay	3.7	37.5	ND	51	4	Qtz/felsp/mont/mica
Armen.	E108	S	MONI clay	1.2	41.2	ND	53	12	Qtz/mont/chl/mica
Moni	E5	S	MONI clay			ND	53	7	Qtz/mont/calc
Moni	E109	S	MONI clay	3.7	52.5	Tr	55	18	Qtz/mont/calc/gy
Pyrgos	E105	S	MONI clay	2.5	50.7	ND	54	16	Qtz/mont
Phinik.	E111	S	MONI clay	5.6	47.5	ND	48	16	Qtz/mont/mica/gy
Troulli	E103	S	PERAPEDHI cl	2.5	50.7	ND	50	12	Qtz/mont/mica/clinopt
Troulli	E104	S	PERAPEDHI cl	1.2	48.7	ND	ND	75	Qtz/chl/mica
Perapd.	E115	S	PERAPEDHI cl	2.5	27.5	ND	34	14	Qtz/mont/mica/attapulgite
Perapd.	E116	S	PERAPEDHI cl	1.8	25.7	ND	35	Tr	Mont/qtz/clinoptinolite
Ardhel.	E8	S	Bentonitic cl	6.2	45.0	ND	53	7	Qtz/mont/chl
Ardhel.	E9	S	Bentonitic cl			ND	44	Tr	Mont/qtz/clinoptinolite
Kellia	E11	S	Bentonitic cl	3.7	58.7	ND	55	5	Qtz/mont/clinopt
Dhrapia	E20	S	Bentonitic cl	3.7	45.5	ND	56	6	Qtz/mont
Parsata	E21	S	Bentonitic cl	3.7	43.7	ND	51	5	Qtz/mont
Kambia	E27	S	Bentonitic cl			Tr	42	5	Qtz/mont/mica/clinopt