General report/Discussion session 6 – Invited lecture: Fabric and engineering properties of saprolites and laterites

Rapport de spécialistes/Séance de discussion 6 – Conférence invitée: Texture et propriétés géotechniques des éluvions et des latérites

LEANDRO M. COSTA FILHO, Enge-Rio S.A., Rio de Janeiro, Brazil
LORENZ DÖBEREINER, Enge-Rio S.A., Rio de Janeiro, Brazil
TACIO M. P. DE CAMPOS, Civil Engineering Department, Catholic University of Rio de Janeiro, Brazil
EURIPEDES VARGAS JR, Civil Engineering Department, Catholic University of Rio de Janeiro, Brazil

SCOPE

The topic "Fabric and Engineering Properties" for tropical soils corresponds to an extremely vast subject which cannot be coverered in a single paper for this Conference. For the purpose of the technical session, this paper includes an introduction with a short summary of the main points of the subject, followed by the presentation of two studies related to specific aspects of interest, namely the microfabric study of a weathering profile and a study of structural anisotropy of a saprolitic soil, both derived from gneissic rocks.

1. INTRODUCTION

Residual soils formed from in-situ weathering of rocks in tropical climates present difficulties in analysis and design due to their extreme variability and complex structural arrangements both at micro and macrofabric levels. Classical soil mechanics has been developed for particulate materials with properties associated with initial porosity (void ratio) and subsequent stress-history. For residual soils developed in place without transportation, the particles and their arrangement suffer a progressive evolution as a consequence of predominantly chemical weathering, resulting in widely varying mineralogy and void ratio.

Figure 1 presented by Vaughan (1988) illustrates the factors controlling the engineering behaviour of transported and residual soils.

The results of several studies have shown that the geomechanical characteristics of undisturbed residual soils very often do not correlate directly with index properties such as consistency limits, percentage of clay size particles, water content, etc, as for transported soils. This is partly due to the difficulty in defining representative grain and void size distributions and partly due to the variability of properties even in a particular sample.

Another important factor to influence the geotechnical behaviour of residual soils is the presence of a weakly bonded structure in the sense described by Vaughan (1985,1988): a component of strength and stiffness which is independent of effective stress and porosity and which behaves as if it was due to physical connections between particles. While it is clear that strong bonds exist in rocks, the presence of weak bonding can be related to observed geotechnical behaviour in several types of soils, particularly residual soils, but also including sedimentary clays and sands (Vaughan, 1985). In residual soils it can be retained from the parent rock, generated during weathering or associated with redeposition of oxides, silicates, etc. A bonded structures is destroyed by remoulding even with unaltered porosity or can be damaged by sampling (the stress-relief effects discussed by Sandroni, 1985a) or effective stress changes during specimen preparation prior to laboratory testing as suggested by Bressani and Vaughan in a paper to this Conference. Microstructure studies in residual soils are particularly relevant in trying to identify the possible origins of bonding.

Bonding is generally associated with:

- the presence of a true cohesion in terms of effective stresses;
- the presence of an "apparent preconsolidation pressure" (Vargas, 1953) indicative of yield, unrelated to stress history or density;
- a stiff response at low stresses and a more plastic behaviour at larger stresses, characterizing a yield surface.

It is clear that the engineening properties of residual soils are greatly influenced by the microstructures (including microfabric, composition of particles and interparticle forces) associated with the weathering process. Baynes and Dearman (1978), studying the weathering of granites, indicated that the resultant microfabric reflected the intensity of weathering. The same authors concluded that varied microfabrics can exist in the same sample reflecting different weathering environments. Collins (1985) based on analysis of microstructures of different types of residual (lateritic and saprolitic) soils also concluded that they are likely to be heterogeneous and with a wide variety of levels of fabric organization present, associated with complex multi-level pore systems. The same author presented a classification schema for microfabric studies of residual soils. In a paper to this Conference, Massey, Irfan and Cipullo tried to relate the behaviour

TRANSPORTED SOILS

THE PARTICLES - Are generated elsewhere and are assumed not to alter with time. Their unit weight, sizes, hardness and surface chemistry.

THEIR INITIAL ARRANGEMENT - Initial void ratio, fabric after deposition and inherent anisotropy.

STRESS HISTORY – Modification of porosity and fabric by the plastic strains occurring due to loading and unloading in geological time. Stress induced anisotropy.

RESIDUAL SOILS

THE PARTICLES - Arrangement and fabric evolve continuously as a consequence of chemical alteration during weathering. Anisotropy inherited from parent rock - e.g. schist.

Soils with swelling clay minerals - vertisols - have different properties from those with no-swelling minerals - Ferruginous, Ferralitic soils and Andosols (lateritic soils).

STRESS HISTORY – Of little importance as the soil has been continuously modified as stress changes have been occuring.

TO WHAT EXTENT AND WHEN HAVE THEIR PARTICLES BECOME STUCK TOGETHER ?

STRUCTURE AND BONDING

WHAT DISCONTINUITIES ARE PRESENT ?

WHAT ARE THEIR STRENGTHS AND INCLINATIONS ?

Fig. 1 - Factors controlling the engineering behaviour of soils (Vaughan, 1988).

of two saprolitic soils from Hong-Kong during triaxial and direct shear tests to the microfabrics observed in thin sections (optical microscope) and associated weathering indexes.

While microstructure of residual soils and associated weathering profiles are of importance to understand their engineering behaviour, macrostructural features in saprolitic soils are in many cases of greater importance for the behaviour of the soil mass. These include:

- structural anisotropy associated with the parent rock (schist, phylite, gneiss, etc);
- presence of relict structures from the original rock, including weakness planes (shear strength and deformability) and permeable or impermeable veins (permeability);
- fissures, joints and other types of discontinuities, slickensided or not;
- presence of holes in the soil which could be associated with laterization processes, intense animal action, pipes formed by internal erosion of softer zones, etc, leading to higher mass permeability.

The remaining of this paper will concentrate in two aspects of those mentioned before:

1) A microfabric study of a weathering profile in residual soil derived from gneiss and its relationship with some engineering charateristics.
2) An investigation of anisotropy of a saprolitic soil derived from a well banded gneiss.

2. WEATHERING OF A GNEISSIC SOIL PROFILE

CHARACTERIZATION OF WEATHERING

Although it is dificult to express the engineering properties of a soil or rock in terms of composition and texture, a knowledge of their mineralogy and fabric is important to an understanding of their geological history and engineering behaviour.

The weathering profile of a rock will clearly show the changes in mineralogy and fabric which develops in various rates and ranges, acording to the environments to which the materials have been exposed.

Different weathering indeces have been proposed for residual soil profiles in the past, for different types of parent rocks, and were tried to relate to engineering properties. The decomposition index Xd has been proposed by Lumb (1962) and used by Baynes and Dearman (1978) for weathered granite. This index was later modified by Irfan (1988). Irfan and Dearman (1978) proposed a micropetrographic index also for granitic soils. Lohnes and Demirel (1979), Tuncer and Lohnes (1977) and Tuncer (1988) found good correlations between sesquioxide content or specific gravity and pore size distribuition with engineering properties of soils devired from basalts and volcanic ashes. Rocha Filho, Antunes and Falcão (1985) tried several chemical and mineralogical indeces as weathering index for a residual profile derived from gneiss and found that the degree of lixiviation gave reasonable correlations with geotechnical properties.

These evidences indicate that a relationship between fabric and engineering behaviour is very complex and, to develop a better understanding, one has to create models to simulate the development and engineering behaviour of weathering profiles. One engineering approach proposed by Vaughan and Kwan (1984) tries to relate weathering to a weakening process of strength and deformability, with the associated in-situ stress-changes.

Another aproach, developed by Dobereiner (1984), for the understanding of the relationship between fabric and engineering behaviour of weak sandstones, which are more simple rock textures, could be used as a model. Discussions on these relationships for sandstones and gneissic rocks are described below.

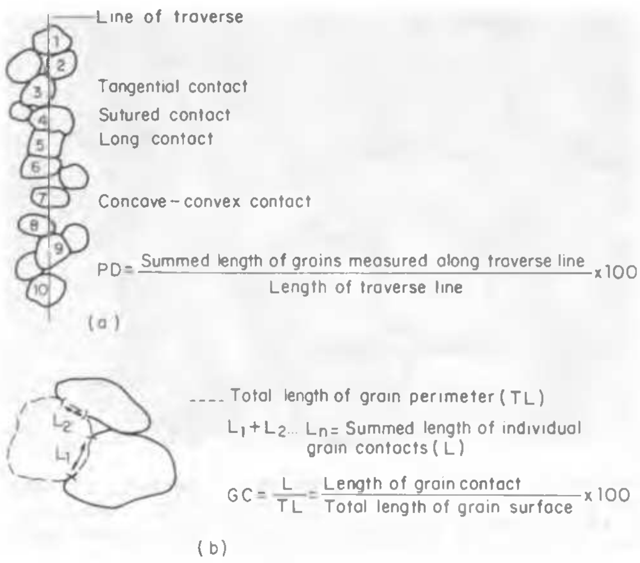


Fig. 2 – Definition of (a) packing density and (b) grain contact.

FABRIC AND WEATHERING PROFILES OF SANDSTONES

Sandstones have, in most cases, a very uniform mineralogy composed essentially of quartz. In these rocks, therefore, the fabric is the most relevant microscopic feature to consider in the interpretation and analysis of the geotechnical properties.

Döbereiner and de Freitas (1986) have quantified several fabric microscopic parameters. However, two main characteristics of the texture from microscopic observations on different types of weak sandstones are potentially useful:

(i) The packing density, defined by Kahn (1956) as the ratio of the sum of the grain length encountered along a traverse across a thin section, to the total length of the traverse (Fig. 2a). Matrix material is not counted, but mineral overgrowths to grains are included in the measured length of a grain.

(ii) The grain contact is the ratio of the length of contact a grain has with its neighbours to its own total length: it is measured in two dimensions and is expressed as a percentage (Fig. 2b).

The relationships between packing density and grain contact with the uniaxial compression strength of saturated samples of sandstones are shown in figures 3a and 3b.

The results shown in figure 3 were obtained from measurements for all grains within an area of thin section selected to be typical and containing more than 100 grains. These figures clearly show that an increase in packing density and grain contacts are related to the strength of sandstones.

The weathering profile of the Bauru sandstones, from the Paraná basin in Southern Brazil is shown by plates 1 to 3, which represent the points 4, 5 and 7 of figure 3. The increase in grain contacts is well illustrated on the thin section photographs. The Bauru sandstone B1, showing 36,7% of grain contact area, is on the top of the weathering profile and has aproximately 26% of matrix. Further down, the B2 and B3 sandstones have respectively 44,3 and 48,8% area of grain contacts and considerably less matrix, in the range of 5 to 10%. The packing density does not correlate as well with strength; as an example the packing of grains has shown in average to be higher in the B2 sandstone than in the B3, which has higher strength. This could also be observed in other sandstone types of figure 3. Hence, the difference in strength displayed by this material can be attributed mainly to differences in the area of grain contact, related to the weathering profile. The alteration of these sandstones show few mineralogical changes. However, an "opening" on the fabric is seen, with decrease in grain contacts, caused probably by

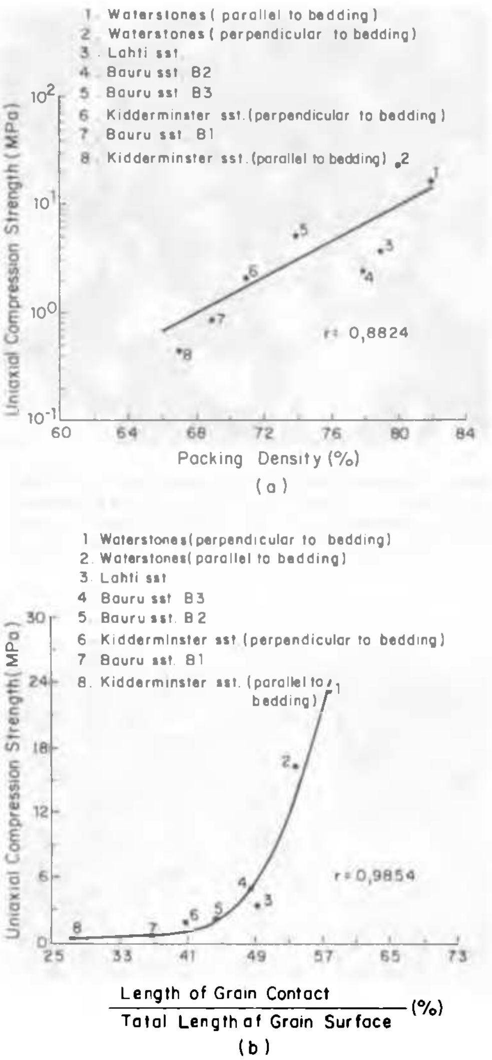


Fig. 3 – Relationships of strength of sandstone with (a) packing density and (b) grain contact.

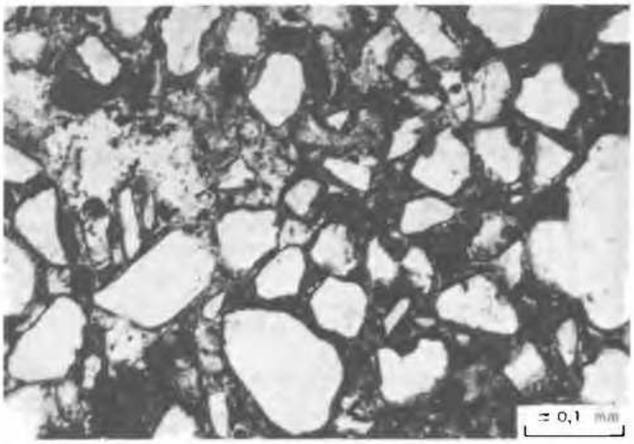


PLATE 1 - Bauru sandstone B1 - composed of 85% of grains of quartz (90%), mica(1%), feldspar (5%) and rock fragments (4%), with 25% clay cement (smectite, kolinite, illite) and iron oxide.

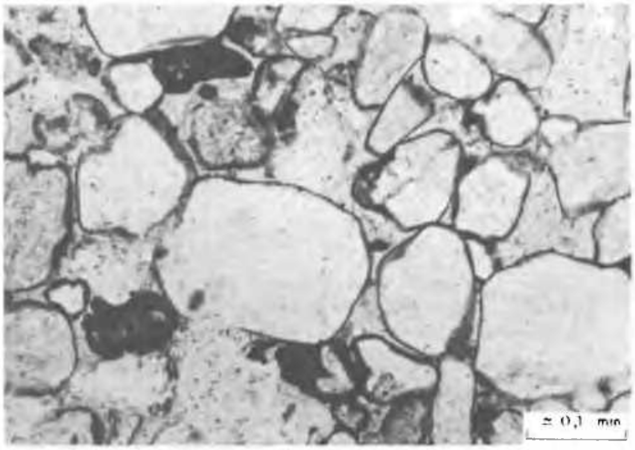


PLATE 2 - Bauru sandstone B2 - composed of 85% of grains of quartz(89%),mica (1%), feldspar (2%) and rock fragments (8%), with less than 5% clay matrix and iron oxide.

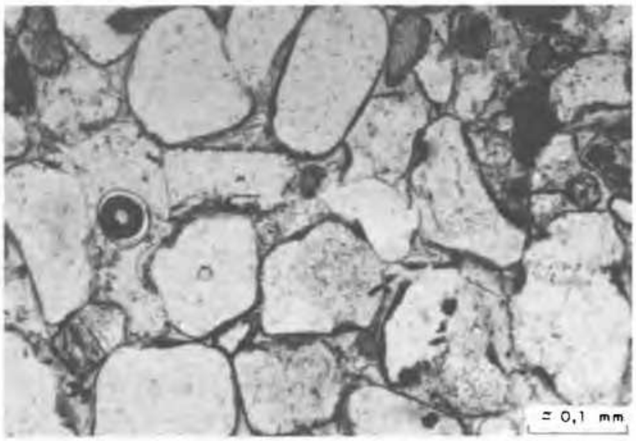


PLATE 3 - Bauru sandstone B3 - composed of 88% of grains of quartz (90%), mica (1%), feldspar (1%) and rock fragments (10%), with less than 5% clay matrix and iron oxide.

stress relief associated to the increase of matrix and/or cement caused by precipitation of iron oxides.

FABRIC AND THE WEATHERING PROFILE OF GNEISS

The weathering profile of a gneissic rock should be expected to be far more complicated than that of a sandstone. This is mainly due to the variable mineralogy, with the presence of quartz, feldspar and mica which have different alteration processes and to the complex metamorphic features generated (banding, microfolding, etc).

A profile of weathering of a gneissic rock at the Experimental Site nr. 2 in the campus of the Catholic University of Rio de Janeiro has been chosen for this study. Data from the site has been presented by Rocha-Filho and Carvalho (1988) and boreholes and trial pits were executed reaching the entire weathering profile. This site is about 200 m away from the Experimental Site nr. 1, which has been studied in detail by Sandroni and Maccarini (1981) and Rocha-Filho et al (1985), among others, with similar weathering profile. In both sites the original rock is a garnet-biotite-plagioclase-gneiss.

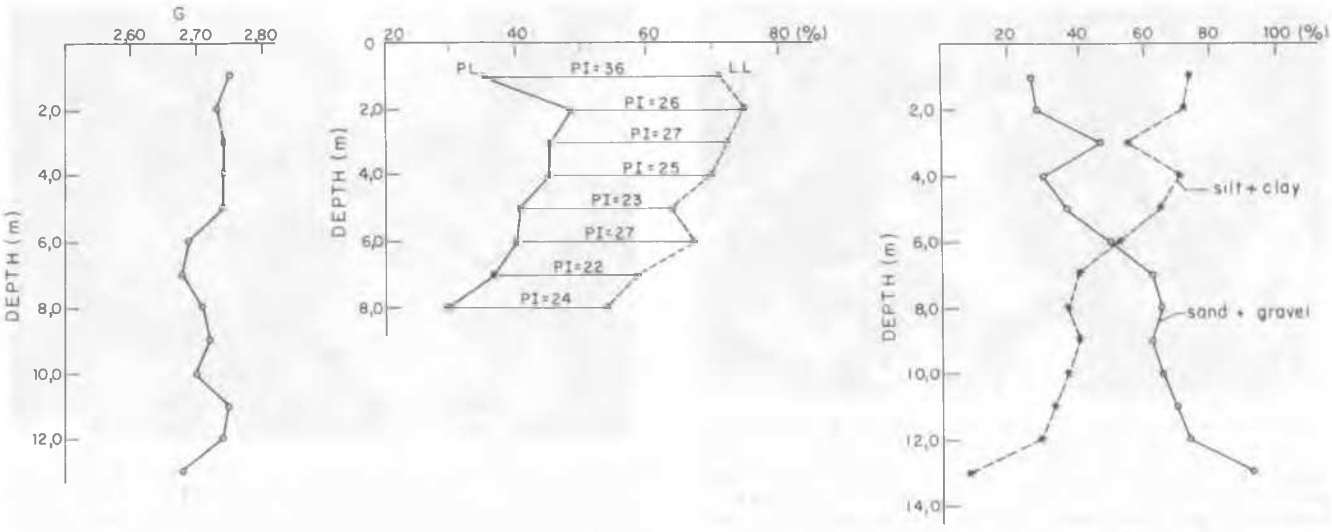
A general characterization of the site has been presented by Sertã (1986).

The profile consists of mature residual soil down to a depth of about 6,5 m followed by a saprolitic soil up to about 25 m with sound rock being found at about 32 m. A pit could be open by hand up to 13 m deep, while refusal was obtained in the SPT at 24 m.

Block samples were taken from the trial pit at depths of 2,5, 7, 9 and 11 m. These samples (with numbers corresponding to the depths) were used for fabric studies and for geotechnical laboratory tests. Variation with depths of conventional grain size distributions, consistency limits and specific gravity of grains obtained by Sertã (1988) are shown in figure 4. Other data from in-situ pressuremeter and cone penetration tests and pile load tests in the upper 7 m are presented by Rocha-Filho and Carvalho (1988) while results of triaxial tests at several depths up to 11 m in unsaturated soil specimens are presented by Marinho (1986).

The macrostructure on samples 2 and 5 is not preserved, making the identification of the gneissic banding from the original rock, difficult to distinguish.

On samples 7, 9 and 11, which show little difference among them, some relict structures can be observed. Few of the mafic bands can be separated from the felsic ones. Laterization can also be seen, with areas of concentrations mainly related to zones with more quartz



(a) Specific Gravity (b) Atterberg limits (c) Coarse and fine soil fractions

Fig. 4 - Characterization of the weathering profile of gneiss at Experimental Site 2 (Sertã, 1988).

grains, or zones supposed to be more permeable. Some bands of finer grained material can also be identified in parts of the samples.

Microfabric studies were carried out using optical microscopy on thin sections, impregnated with araldite, of samples 2, 5, 7, 9 and 11. Plates 4 to 8 show a sequence of photographs of the thin sections.

It can be observed that the residual soil near the surface, as shown in Plate 4, indicates the presence of a completely collapsed microstructure, with small quartz fragments floating in a clayey matrix (mainly kaolinite and iron oxides). No grain contacts are observed and packing density is very low, working as a low anisotropic clay sandy soil. As the depth increases, larger quartz grains are observed in the residual soil; in some areas few tangential quartz grain contacts are seen, and the microstructure is not always completelly collapsed (Plate 5). The percentage of fine grained matrix is still larger than quartz sand angular grains, as also shown in the grain size distribution with depth in figure 4. The lower boundary of the mature residual soil is now close, with the transition zone less than 1 m thick.

Further below, at 7 m depth, already in the saprolitic soil, the general aspect of the fabric is well marked (Plate 6). The fabric is preserved, the first long quartz grain contacts can be observed and the percentage of the fine grained fraction is smaller that the coarse grained. The mica, sellimanite and feldspar grains can be identified in an altered state. Two meters below (Plate 7), some slightly open long sutured quartz grain contacts are seen. The presence of iron oxides is more frequent in this particular sample. At 11 m depth (Plate 8) further small changes are observed: incipient microcracks, together with other more open ones, are seen in quartz grains, indicating probably to be a stress relief feature. The altered mica, sillimanite and feldspar textures are better defined.

PLATE 4 - Residual soil of gneiss 2 m depth. Quartz grains (± 30%), floating in a clay (mainly kaolinite) and iron oxide matrix (± 70%).

To quantify the alteration of the different mineral types present, total chemical analysis of the same profile were obtained by Sertã (1988) and are presented in figure 5. The MgO variations with depth show that the changes in MgO are related to the presence of mica and indicates that a great proportion of the Mg was lixiviated down to aproximately 15 m deep.

The comparison of K2O, Na2O and CaO relationships confirm that K feldspar is more resistent to alteration than the plagioclase, with higher percentagens of Na and Ca occurring only below 30 m depth, where sound rock is present.

The K feldspar are present below 15 to 20 m, as indicated by the higher percentages of K2O at these levels.

Small variations with depth are shown in figure 5 for the Fe2O3, with higher values occurring at the superficial, more lateritic layer. Ho-

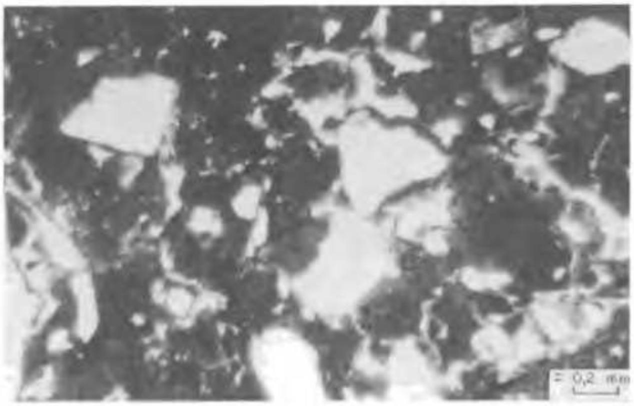


PLATE 5 - Residual soil of gneiss 5 m depth. Quartz grains (± 40%), floating in a clay (mainly kaolinite and illite) and iron oxide matrix (± 60%). The fabric is still collapsed, however some tangential quartz grain contacts are already seen.

PLATE 6 - Saprolitic soil of gneiss 7 m depth. Quartz (± 50%), sillimanite (± 25%) and feldspar (± 15%) grains are seen in a better preserved fabric. Mica occurs as trace mineral and a few long quartz grain contacts are observed. Iron oxide / clay matrix and / or cement are also present (± 10%).

wever, within the small oscillations observed, it should be noticed that at 9 m the percentage of Fe_2O_3 is higher than at 7 and 11 m in agreement with the descriptions of the thin sections (plates 6 to 8).

Figure 8, shows X-ray difraction analysis performed (Brito, 1981) on a weathering profile of a borehole drilled in the same material at Experimental Site 1. The results clearly show a modification on ths mineralogy during the weathering process. At 24 m depth plagioclase, microcline, mica and quartz are present. At 20 m depth the plagioclase is not present and an increase in kaolinite is observed. Mica and microcline and sillimanite are still occuring. Between 10 and 13 m depth the mica and microcline start disapearing and above 6 m mainly kaolinite and quartz are the constituents: very small percentages of goethite and few weathered sillimanite grains are also observed.

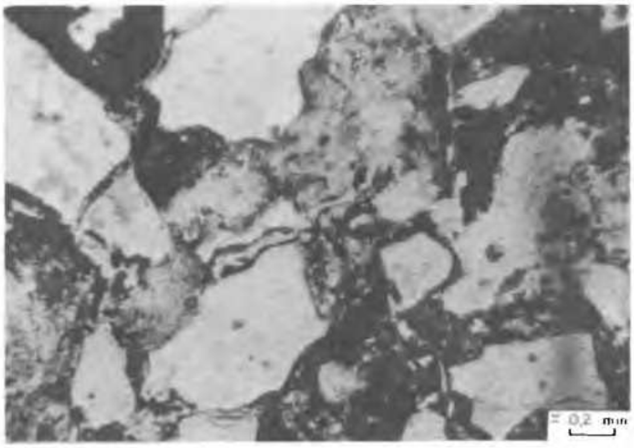


PLATE 7 - Saprolitic soil of gneiss 9 m depth. Quartz (± 40%), sillimanite (± 10%), feldspar (± 20%) and mica (± 5%) grains are observed with few sutured contacts. Iron oxide / clay cement more frequent in this sample (± 20%).

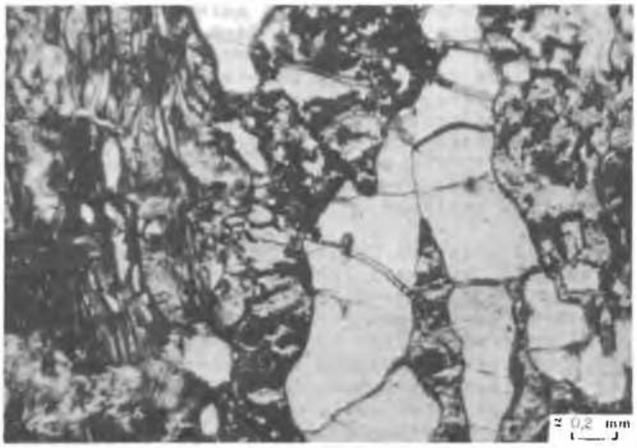
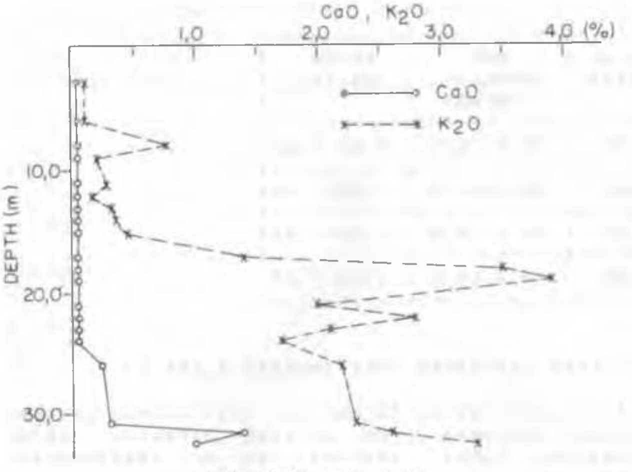


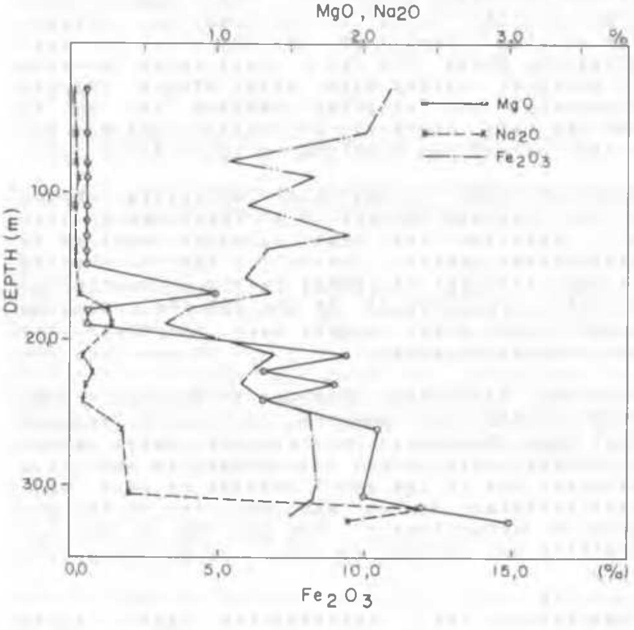
PLATE 8 - Saprolitic soil of gneiss 11 m depth. Quartz (± 40%), sillimanite (± 10%), feldspar (± 35%) and mica (± 5%) with a clay /iron oxide (± 10%) matrix. Quartz grains present in sutured contacts, with incipient microcracks.

GEOMECHANICAL CHARACTERISTICS OF THE GNEISS WEATHERING PROFILE

In order to try to relate the fabric and weathering studies described above to geomechanical characteristics of the weathering profile of gneiss, a series of laboratory tests were carried out. These consisted of drained triaxial tests on saturated specimens and constant head permeability tests in the triaxial cell, using the block samples taken at 5, 7, 9 and 11 m deep in the Experimental Site 2. The sample characteristics are shown in table 1.



(a) CaO and K2O



(b) MgO , Na2O and Fe2O3

Fig. 5 - Variation of percentage of chemical elements with depth at Experimental Site 2 (Sertã,1988).

o Stress-strain characteristics

Stress-strain curves of specimens vertically cut, saturated and then consolidated to 25 kPa before drained shearing are shown in Figure 7. A clear distinction in the stress-strain relationships can be noticed, with the shallower sample (5) presenting a plastic behaviour while those taken below 7 m deep showed a well defined peak strength. On the other hand, along the weathering profile no marked changes were observed in the pattern of contraction before maximum strenght/ yielding is reached, followed by dilation.

Considering the microstructures shown in Plates

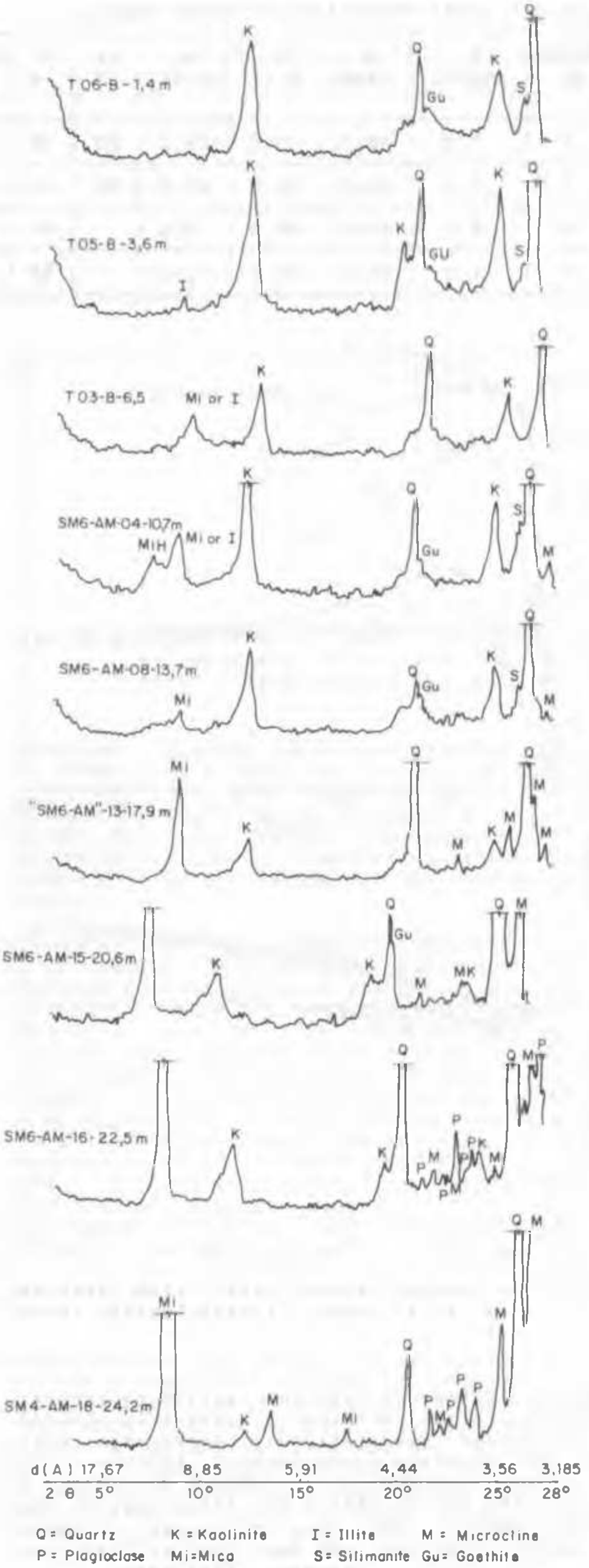


Fig. 8 - X-ray difraction analysis of gneissic weathering profile at Experimental Site 1 (Brito, 1981).

Table 1 - Index Properties of Block Samples

BLOCK NR	% GRAVEL	% SAND	% SILT	% CLAY	LL %	PL %	SPECIFIC GRAVITY	DRY DENSITY (kN/m3)	VOIDS RATIO
5	1,0	28,0	5,0	66,0	53	33	2,77	14,2-14,7	0,88-0,92
7	7,0	42,0	25,0	26,0	39	19	2,67	12,4-13,4	0,99-1,14
9	2,0	65,0	28,0	5,0	-	NP	2,72	13,1-13,8	0,98-1,09
11	1,0	59,0	30,0	10,0	-	NP	2,75	12,4-14,2	0,94-1,21

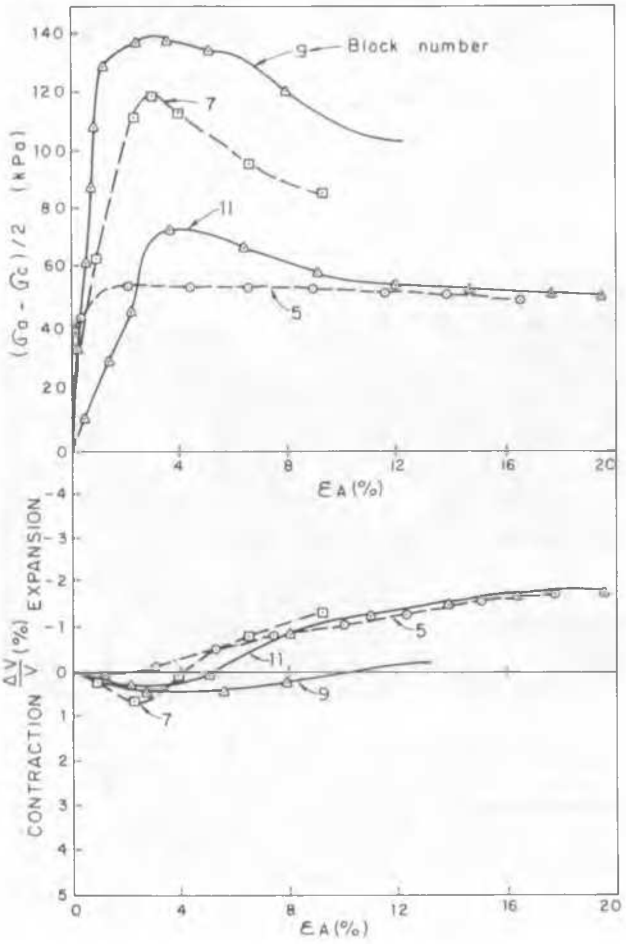


Fig. 7 - Stress-strain curves from drained triaxial tests in Experimental Site 2.

4 to 8, it appears that the increasing content of quartz grain contacts / increasing size of quartz grains qualitativelly correlates well with the observed stress-strain pattern. In the mature residual soil (sample 5, plates 4 and 5) the quartz grains are "floating" on the clayed matrix and no relict or primary "bonding", characterized by a brittle behaviour under contraction, occurs. This relict "bonding" / stress-strain association is, on the other hand, clearly seen in the saprolitic soil, particularly in sample 9, which seems to be less weathered than samples 7 and 11.

It is interesting to mention that stress-strain curves obtained from drained triaxial tests (Marinho, 1986), carried out on unsaturated specimens from the same block samples used for the present testing series, showed plastic or strain hardening behaviour. These samples were sheared after consolidation under cell pressures varying between 75 and 400 kPa; for cell pressures above 200 kPa a continuous increase in deviator stress with axial strain (strain hardening) was observed whereas for 75 to 150 kPa cell pressures a constant maximum deviator stress was attained (plastic behaviour).

Sandroni (1981), using data from several depths of the weathering profile at Experimental Site nr 1, reported that peak strength occurred in unsaturated gneissic saprolitic samples sheared in the triaxial equipment after consolidation at cell pressures of 50 and 100 kPa. Samples consolidated under higher cell pressures did not show brittleness.

From the test data obtained by Marinho (1986) using unsaturated samples, it can be assumed that the changes in cell pressure would be approximately equivalent to changes in effective stresses due to the small changes in water content suffered by the specimens and to the degree of saturation of 60% and 75% for the saprolitic and mature residual soils respectively.

Considering the consolidation levels above which the unsaturated samples lost their brittle characteristics, it is reasonable to suggest that relict or first order "bonding" in this gneissic residual soil would be destroyed by changes in isotropic effective stresses above 75 kPa. Whether this can be related or not to sampling stress relief effects, is not known. It is however interesting that the above figure is of the same order of magnitude as the critical effective confining pressure mentioned by Massey, Irfan and Cipullo in their paper to this Conference. This critical pressure defined a region below which the granitic saprolitic soil from King's Park, Hong-Kong, showed increased strength, both when tested under drained and undrained conditions in the triaxial equipment.

On the other hand, swelling the saturated specimens to 25 kPa does not seem to have destroyed the "bonded" structure.

The results in figure 7 indicate a tendency for the saturated saprolitic soil specimens to show

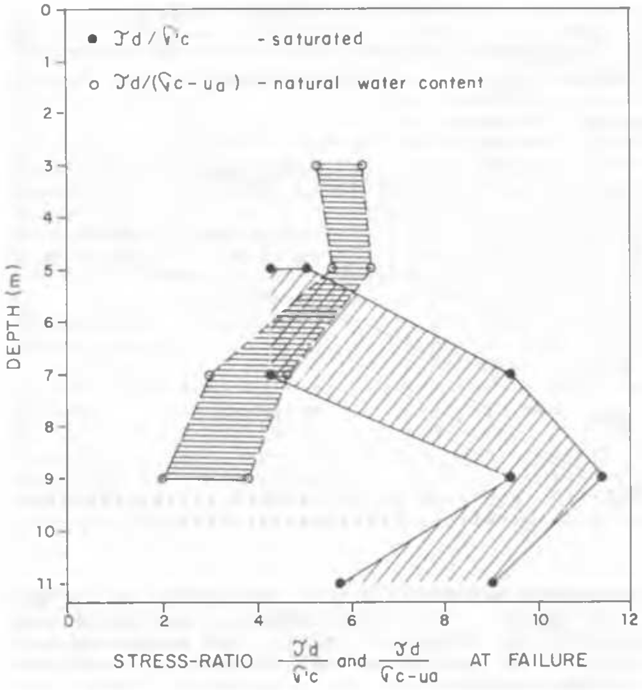


Fig. 8 – Variation of normalized peak strength with depth – Experimental Site 2.

a relation between stiffness and peak strength. The stiffer behaviour at small strains of the mature residual soil (sample nr 5) has also been observed by tests in unsaturated specimens by Marinho (1986) and might be associated to the existence of a non-relict type of bonding. This could be formed by a chemical bond related to the laterization process and indicated by the higher percentage of iron oxides in this level.

o Shear strength

Shear strength values obtained from drained triaxial tests on saturated and unsaturated samples are plotted against depth in figure 8. The stress ratio at failure for the saturated specimens is defined as the ratio between the peak deviator stress and the effective consolidation stress. For the unsaturated specimens, this stress ratio is defined as the ratio between the deviator stress at failure and the difference between confining total stress and the pore air pressure.

The stress ratio range for the saturated soil shown in figure 8 was obtained from specimens cut vertically, horizontally and with the banding paralell and perpendicular to the horizontal plane, without any consistent indication of anisotropy. The range shown for the unsaturated soil corresponds to vertically cut samples loaded after consolidation at confining total stress between 75 and 200 kPa (Marinho, 1986).

The trend in increasing stress ratio at failure with depth shown by the saturated saprolitic samples can be related to an increase in grain contacts. However, only this feature, noticed in plates 4 to 8, does not explain the decrease in stress ratio from sample 9 to 11. One explanation could be the presence of a greater amount of iron oxides in samples 9, as mentioned previously. Another cause could be a higher weathering degree of the components of sample 11.

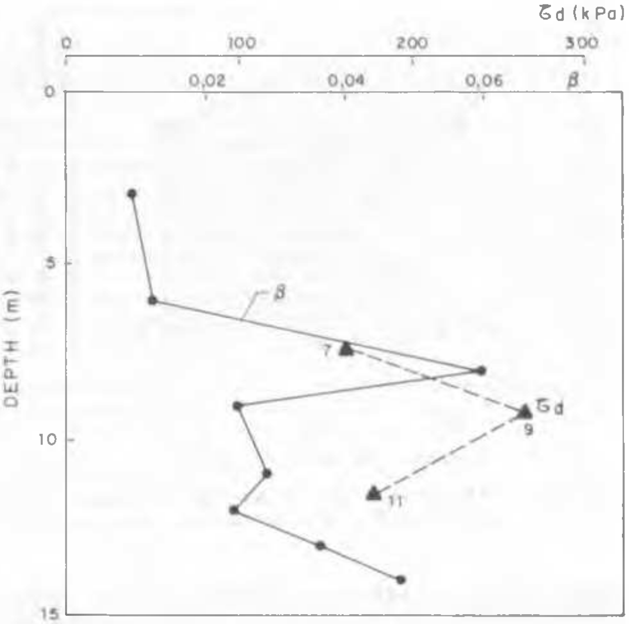


Fig. 9 – Variation of mean saturated peak strength and lixiviation index with depth – Experimental Site 2.

Rocha-Filho et al. (1985) noticed that lixiviation indeces provided good correlations with engineering properties of the saprolitic gneissic soil from the Experimental Site 1 at PUC/RJ. One of such chemical weathering indeces, the index β, varies from 1, in sound rock, towards 0 as the degree of weathering increases. Sertã (1986) determined the variation of β with depth, from a boring located about 1,5 m from the pit where the block samples were obtained. Figure 9 reproduces part of such data. Average values of drained strength were also plotted against depth in this figure. Both the lixiviation index and the average strength show the same trend, providing further evidence that the lower strength obtained in the testes on block 11 are associated to a higher degree of weathering.

Comparing the results for the saturated and unsaturated specimens shown in figure 8, the higher stress ratios observed for the unsaturated mature residual soil may be related to higher consolidation stresses and suction effects in the unsaturated samples or to loss of chemical bonding in the saturated ones. From the evidence of very stiff behaviour of the saturated specimens of sample 5 in figure 7, it seems more likely that the initial state of stress would be the responsible.

On the other hand the higher values of strength for the saturated saprolitic soil are believed

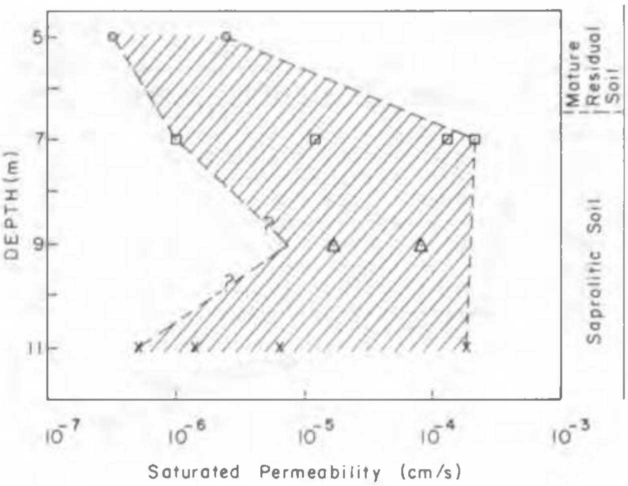


Fig. 10 - Variation of saturated permeability with depth - Experimental Site 2.

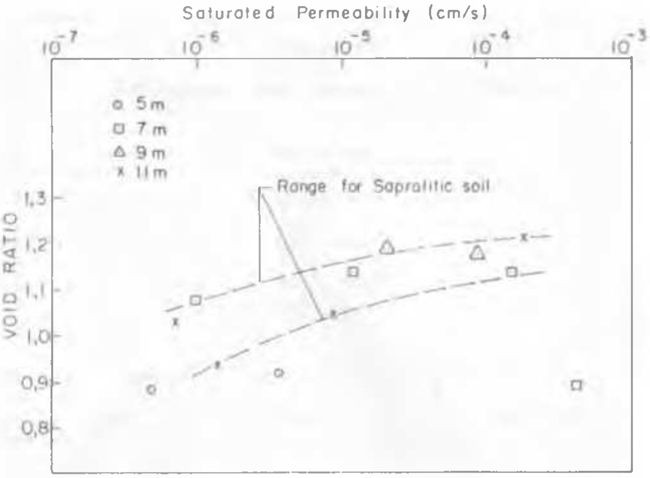


Fig. 11 - Variation of permeabilityu with void ratio - Experimental Site 2.

to be mostly related to bonding disruption / grain breakage during consolidation at higher stress in the unsaturated soil.

o Permeability

The results from the permeability tests carried out in the triaxial cell under consolidation pressures of 10 kPa are shown in figure 10. The very large scatter obtained could be related to the small specimens used in the tests (D = 38 mm, h = 80 mm) and would reflect changes in microstruture from point to point in the same block sample. Within the scatter, the results do not show any trend in variation with depth for the saprolitic samples, in agreement with data previously collected by Costa-Filho and Vargas Jr (1985). The relatively low values of permeability in the mature residual soil (sample nr 5) are consistent with the absence of porous structure which can be observed only in the superficial 1 to 2 m. The results in figure 10 include specimens with banding inclined at different angles with the vertical but no consistent anisotropy indication could be found. However, the scatter observed in the results can be related to variations in the conventional void ratio as shown in figure 11. This is to be expected since the permeability should be more affected by the void sizes and distribution than by the grain mineralogy or contacts.

COMPARISON OF THE WEATHERING OF SANDSTONES AND GNEISS

The different weathering behaviour of quartz sandstones and gneissic rocks, are mainly related to the distinct mineralogy of both rock types. Quartz grains in both materials are chemicaly stable, however feldspar and micas in gneissic materials show a different sequence of alteration, as indicated in the mineralogical analysis (Figures 5 and 6). Therefore the good fabric relationships with engineering behaviour obtained on sandstones, would be difficult to quantify precisely in gneisses, since feldspars and micas suffer alteration at different rates. The distinction of weathered and unweathered minerals is far too simple to represent the several stages present in the alteration process.

In order to obtain a good relationship between grain contacts and engineering properties for these gneissic rocks, one would have to consider the grain contact area for these different mineral alteration levels. This would be a difficult task to quantify.

Nevertheless, the fabric presented for the weathering profile of gneiss investigated, associated with the chemical analyses performed, have shown a qualitative explanation for the observed geomechanical behaviour, particularly, deformation and strength. Therefore, it is important to understand the several variables of the fabric which will control the engineering behaviour of these materials. In this sense the grain contact model developed for sandstones could in part help us to understand further the engineering behaviour of residual soils.

3. ANISOTROPY OF A GNEISSIC SAPROLITIC SOIL

Structural anisotropy inherited from the parent rock is commonly observed at macrostructural level in saprolitic soils derived from metamorphic (schist, phylite, gneiss, slate, etc) and sedimentary (shale, mudstone, etc) rocks. This type of anisotropy is distinct from that imposed to the mass by the presence of relict features such as permeable or impermeable layers, weak layers, joints, etc.

Despite its potential importance for geotechnical studies, only a limited amount of data is available in the literature.

Table 2 summarizes data of shear strength parameters from different types of saprolitic soils derived from metamorphic rocks.

The results show in general the occurence of anisotropy of shear strength parameters, with

Table 2 - Shear Strength Parameters for Saprolitic Soils from Metamorphic Rocks

PARENT ROCK	MACROSTRUCTURE	STRENGTH FROM DIRECT SHEAR TESTS		WATER CONDITION	REFERENCE
		PARALLEL	PERPENDICULAR		
Ferritic quartzite	Laminated (silty sand)	c'= 20 kPa Ø'= 37o	c'= 50 kPa Ø'= 44o	Partially saturated	Sandroni (1985b)
Micaceous quartzite	Schistose (sandy silt)	c'= 40 kPa Ø'= 22o	c'= 45 kPa Ø'= 27o	Partially saturated	Sandroni (1985b)
Migmatitic quartzite	Banded (mica rich bands)	c'= 40 kPa Ø'= 20o	c'= 52 kPa Ø'= 23o	Partially saturated	Campos (1974)
		c'= 30 kPa Ø'= 21o	c'= 49 kPa Ø'= 22o	Submerged	Campos (1974)
Schist	Laminated (silty sand)	c'= 78 kPa Ø'= 28o	c'=100 kPa Ø'= 27o	Partially saturated	Durci and Vargas(83)
Phylite (micaceous)	Schistose (silt)	c'= 10 kPa Ø'= 28o	c'= 60 kPa Ø'= 41o	Partially saturated	Durci and Vargas(83)

increasing difference for the more laminated materials. In agreement with that, the gneissic saprolitic soil from Experimental Site 1 does not show any definite anisotropy in direct shear tests (Sandroni and Maccarini, 1981). For a granitic saprolitic soil, as expected from the lack of preffered orientation of the grains, Cheung et al (1988) found similar parameters for samples sheared in the horizontal and vertical directions.

Data from anisotropy in compressibility and deformability of saprolitic soils is very scarce and only oedometer tests with samples oriented in different directions are presented, without conclusive results.

In relation to permeability, very few test results are reported in the literature, even considering the possible importance of anisotropy in relation to stability of slopes in saprolitic soils from metamorphic rocks. Values obtained by Sowers (1963), in a limited series of tests of gneissic saprolitic soil indicate in average, a higher permeability in the direction parallel to banding, 2-4 times larger than perpendicular to it. Mori et al (1978) indicate that for the saprolitic soil from gneiss at Itumbiara dam the permeability along the banding is about 1,4 times that across the banding. The results of the tests presented above for the samples from Experimental Site 2 did not indicate any marked anisotropy in permeability.

Some data has been obtained from a series of tests carried out to investigate the anisotropy of a well banded gneiss from Chapéu d'Uvas site and tried to relate to fabric study.

The original rock is a pre-cambrian kinzigite biotite garnet gneiss, showing at a macro scale a well marked anisotropy, with regular alternation of felsic and mafic centimetric bands (see plate 8). The weathering profile in the area is characterized by 1,5 m of a silty clay mature residual soil underlain by a silty-sandy saprolitic soil reaching 30 m depth. The transition between the saprolitic soil is laterally stepped and is characterized by a zone of approximately 2 m of weathered gneiss, before reaching sound rock.

PLATE 9 - Macrostructure of saprolitic soil of gneiss will banded structure.

The samples used in this study were obtained at a depth of about 8,0 m in the profile.

FABRIC STUDIES

The fabric of the saprolitic soil is shown in plates 10 and 11, obtained by photographs on impregnated thin sections prepared perpendicular to banding. The well marked anisotropy observed in the macroscale (plate 9) is not well defined, due to the state of weathering of the material. The relation between the fine and coarse grained fractions is above 50%, indicating that the fine grain fraction is probably controlling the engineering behaviour of the material.

Both plates were obtained of samples from the same block, confirming that local variations in fabric of the saprolitic soils are frequent.

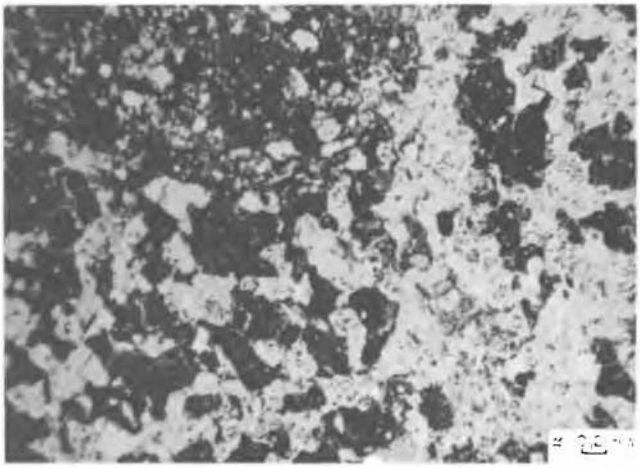


PLATE 10 - Saprolitic soil of a kinzigita gneiss - Quartz (± 20%) and trace mica grains are observed in a matrix probably of clay minerals (± 50%) and iron oxide (± 30%). The orientation of grains is not predominant.

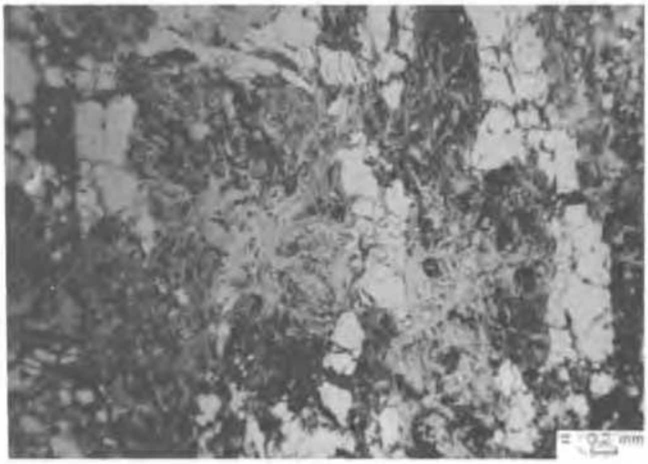


PLATE 11 - Saprolitic soil of a kinzigite gneiss - Quartz (± 30%) and mica (± 15%) grains are observed in a matrix probably of clay minerals (± 40%) and iron oxide (± 15%). The orientation of quartz grains are clearly seen in a "mass" of matrix.

Plate 10 shows a non oriented fabric and a larger percentage of collapsed matrix. On plate 11, the quartz grains bands show some orientation, more grains of mica are present and a small decrease in the percentage of matrix.

GEOMECHANICAL CHARACTERISTICS

The laboratory tests carried out consisted of multiple stage triaxial and direct shear tests and oedometer tests. For the triaxial tests, saturated specimens were used, while the direct shear and oedometer specimens were tested at natural water content and submerged. For the oedometer and direct shear tests the specimens were moulded with their axis parallel and perpendicular to the banding. For the triaxial tests specimens were prepared with banding in the horizontal direction and inclined 45o to horizontal. A series of constant head permeability tests was carried out in the triaxial cell using specimens consolidated at different cell pressures and with different inclinations. The sample characteristics are shown in table 3.

Table 3 - Index Properties of Block Samples

% SAND	% SILT+CLAY	LL %	PL %	SPECIFIC GRAVITY	VOIDS RATIO
28,0	52,0	54	15	2,71	1,23 - 1,53

The results of the oedometer and permeability tests are shown in figures 12 and 13 respectively. The shear strength parameters obtained by linear regression from the direct shear and triaxial tests for the stress range of 25 to 300 kPa are presented in table 4.

All test results show essentially no influence of structural anisotropy on the geomechanical characteristics of this soil. This is in general agreement with the fabric observations and may be due to the advanced stage of weathering of the material, despite the anisotropic impression givem by the macrostructure.

Even considering the limited number of tests of the present series, these results and those quoted before might indicate that structural anisotropy is not a dominant factor for saprolitic soils of gneiss at an advanced staghe of weathering say with more than about 50% of fines, at least not as much as for soils derived from other metamorphic rocks. Also, data is scarse for the less weathered material in which the anisotropic features might be more preserved.

4. FINAL REMARKS

The topic "Fabric and Engineering Properties" for tropical soils correspondo to an extremely vast subject which cannot be covered in a single paper to this Conference. The purpose of this paper was to present a contribution to discussion of possible relashionships between fabric, weathering characteristics and engineering behaviour. The authors are fully aware of the limitations of the results obtained, particularly considering the variability of structure at microstructural level and the small number of samples tested.

It seems that while for relatively simple structural arrangements, such as weathered sandstones, some relationships can be observed with engineering behaviour, for more complex structures such as a saprolitic soil from gneiss, these simple models have only a qualitative meaning. Nevertheless, both microstructural observations and associated weathering indeces seem to at least qualitatively explain some observed engineering behaviour.

Table 1 - Shear Strength Parameters

TYPE OF TEST	WATER CONDITION	DIRECTION OF FAILURE IN RELATION TO BANDING	c′ (kPa)	Ø′ (degrees)
Direct shear	Natural	Parallel	45	35
Direct shear	Natural	Perpendicular	38	38
Direct shear	Submerged	Parallel	27	28
Direct shear	Submerged	Perpendicular	27	28
Triaxial	Saturated	Parallel	20	28,5
Triaxial	Saturated	45 degrees	10	31

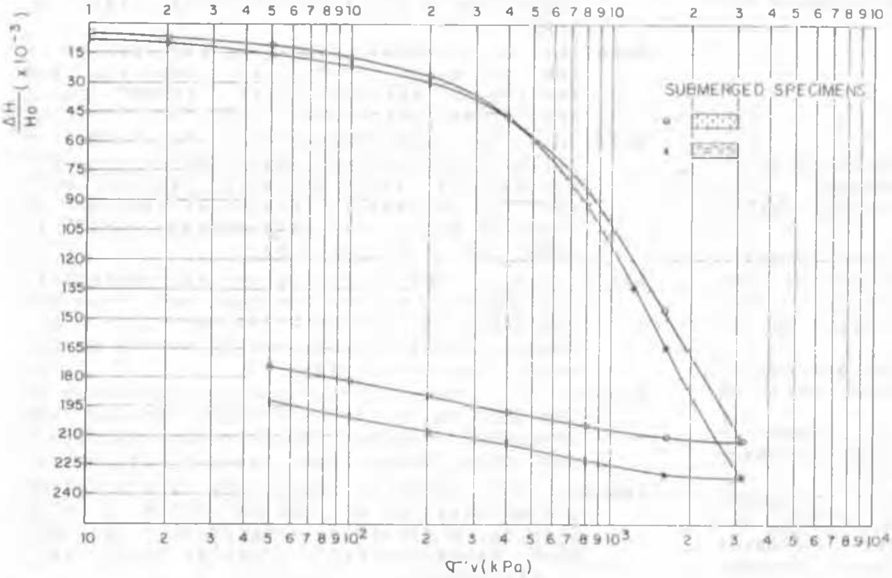


Fig.12 - Oedometer tests in a gneissic saprolitic soil from Chapéu d'Uvas site.

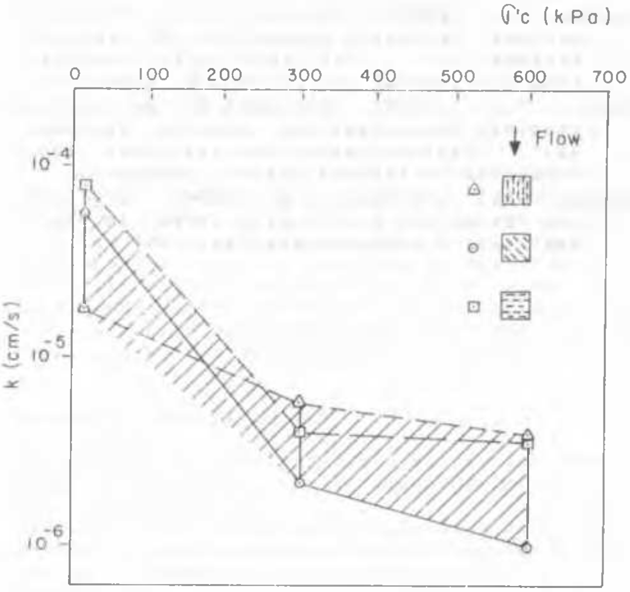


Fig. 13 - Constant-head permeability tests in gneissic saprolitic soil from Chapéu d'Uvas site.

On the other hand, macrostructural features seem to be potentially more influencial to the behaviour of saprolitic soil masses.

It appears that further studies on saprolitic and residual soils need necessarily to be supported by fabric interpretation, in order to understand the engineering behaviour of the materials. It is recomended that not only thin section should be used but also scanning electron microscopy to visualize interparticle relationships of the fine grained fraction and pore sizes and shapes.

It seems also to be necessary to develop further work in the altered rock side of the weathering profile, to complement the knowledge of weak weathered gneissic rocks.

5. ACNOWLEDGEMENTS

The authors are grateful to Prof. Franklin Antunes for his useful contributions and discussions, and to Enge-Rio for the support given for the preparation of the paper. This paper is part of a general study about Slope Stability in Residual Soils developed at PUC-RJ with funds provided by IDRC (Canada).

8. REFERENCES

Baynes, F.J. and Dearman, W.R. (1978) - The relationship between the microfabric and the engineering properties of weathered granite - Bulletin of the IAEG, nr. 18.

Brito, A.T. (1981) - Chemical and mineralogical study of a wathering profile in a migmatitic gneiss of experimental site nr. 1 at PUC-RJ - M.Sc. thesis, Catholic University of Rio de Janeiro (in portuguese).

Campos, T.M.P. (1974) - Shear strength of micaceous residual soils - M.Sc. thesis, Catholic University of Rio de Janeiro (in portuguese).

Collins, K. (1985) - Towards characterization of tropical soil microstructures. 1st Int. Conf. Geomechanics in Tropical Soils, vol. 1, Brasilia.

Costa-Filho, L.M. and Vargas Jr., E.A. (1985) - Peculiarities of in-situ behaviour of tropical soils: hydraulic properties. Progress Report, Committee on Tropical Soils, ISSMFE.

Döbereiner, L. (1984) - Engineering geology of weak sandstones - Ph.D. Thesis, Univ. of London.

Döbereiner, L.; and Freitas, M.H. (1986) - Geothechnical properties of weak sandstones - Geotechnique, vol. 36, nr. 1.

Durci, C.L. and Vargas, M. (1983) - Strength and compressibility of residual soils derived from phyllites - Internal Research Report, Soil Mechanics Laboratory, University of São Paulo.

Irfan, T.Y. (1988) - Fabric variability and index testing of a granitic saprolitic soil - 2nd Int. Conf. Geomechanics in Tropical Soils, vol. 1, Singapore.

Irfan, T.Y. and Dearman, W.R. (1978) - Engineering classification and index properties of a weathered granite - Bulletin of the IAEG, nr. 17.

Kahn, J.J. (1956) - The analysis and distribution of the properties of packing in sand-size sediments: part 1, on the measurement of packing in sandstones - Journal of Geology, vol. 64.

Lohnes, R.A. and Demirel, T. (1973) - Strength and structures of laterites and lateritic soils. Engineering Geology, vol. 7, nr. 1.

Lumb, P. (1962) - The properties of decomposed granite - Geotechnique, vol. 12.

Marinho, F. (1986) - Stiffness evaluation of a gneissic residual soil under small strain - M.Sc. thesis, Catholic University of Rio de Janeiro (in portuguese).

Mori, R.T.; Freitas Jr., M. and Shayani S. (1976) - Geothecnical properties of residual soils from the foundations of Itumbiara dam. XI Brazilian Seminar on Large Dams, Fortaleza (in portuguese).

Rocha Filho, P.; Antunes, F. and Falcão, M.F.G. (1985) - Qualitative influence of the weathering degree upon the mechanical properties of an young gneiss residual soil - 1st Int. Conf. Geomechanics in Tropical Soils, vol. 1, Brasilia.

Rocha-Filho, P. and Carvalho, J.B.Q. (1988) - General Report: Building Foundation in Tropical Lateritic and Saprolitic Soils - 2nd Int. Conf. Geomecanics in Tropical Soils, vol. 2, Singapore.

Sandroni, S. (1981) - Residual soils: research carried out at PUC-RJ - Brazilian Seminar on Tropical Soils in Engineering, vol 2, COPPE-UFRJ (in portuguese).

Sandroni, S. (1985a) - Stress-relief effects in gneissic saprolitic soils - 1st Int. Conf. Geomechanics in Tropical Soils, vol. 3, Brasilia.

Sandroni, S. (1985b) - Sampling and testing of residual soils in Brazil. Sampling and Testing of Residual Soils, ISSMFE, Scorpion Press, Hong-Kong.

Sandroni, S. and Maccarini, M. (1981) - Triaxial and direct shear tests in an occurrence of young gneissic residual soil rich in feldspar. Brazilian Seminar on Tropical Soils in Engineering, vol. 1, COPPE-UFRJ (in portuguese).

Sertã, H.B. (1986) - Geological and geotechnical aspects of the residual soil from Experimental Site nr. 2 at PUC-RJ - M.Sc. thesis, Catholic University of Rio de Janeiro (in portuguese).

Sowers, G. (1963) - Engineering properties of residual soils derived from igneous and metamorphic rocks. 2nd Pan-American Conf. Soil Mech. Found. Eng., vol. 1, São Paulo.

Tuncer, F.R. (1978) - Pore size distribution characteristics of tropical soils in relation to engineering properties - 2nd Int. Conf. Geomechanics in Tropical Soils, vol. 1, Singapore.

Tuncer, F.R. and Lohnes, R.A. (1977) - An engineering classification of certain basalt - derived lateritic soils. Engineering Geology, vol. 11, nr. 4.

Vaughan, P.R. (1985) - General report: Mechanical and hydraulic properties of in-situ residual soil. 1st Int. Conf. Geomechanics in Tropical Soils, vol. 3, Brasilia.

Vaughan, P.R. (1988) - Charactherising the mechanical properties of in-situ residual soil. Keynote Paper, 2nd Int. Conf. Geomechanics in Tropical Soils, Singapore.

Vaughan, P.R. and Kwan, C.W. (1984) - Weathering, structure and in-situ stress in residual soil - Geotechnique, vol. 34, nr. 1.