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MICROPETROGRAPHIC AND ENGINEERING CHARACTERIZATION OF A WEATHERED GRANITE[1]

by

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(3 figures)

RESUME.- Les sept niveaux d'altération d'un même granite de Hingston Down, dans le Sud-Ouest de l'Angleterre, ont été qualifiés par un indice micropétrographique déterminé par analyse modale, et par un indice de microfracturation déterminé en comptant les microfractures le long d'une ligne tracée sur une lame du matériau rocheux. Ces indices se rapportant au matéraiu rocheux sont corrélables avec une série d'indices de classification basés sur des essais et avec les valeurs géomécaniques du matériau. Les propriétés géomécaniques du matériau peuvent être prévues de manière fiable à partir des résultats d'analyses microscopiques quantitatives.

ABSTRACT.- The seven stages of weathering of a single granite from Hingston Down in the south-west of England have been quantified in terms of a micropetrographic index determined by modal analysis and a microfracture index determined by counting microfractures on a linear traverse of a thin slice of the rock. These indices relating to the rock material are correlatable with a range of classification test indices and engineering design values of the rock material. Material properties may confidently be predicted from the results of quantitative microscopical analysis.

INTRODUCTION

The engineering petrography of the weathering profile in a single granite from Hingston Down in the south-west of England has been described and quanfied in terms of micropetrographic and microfracture indices. Seven weathering stages of rock material have thus been characterized, and for each stage a comprehensive range of index tests and engineering design tests have been carried out (IRFAN & DEARMAN, 1978a, b). The purpose of the present paper is to present the results of the determination of relationships that exist between microscopical and engineering properties of each stage.

Micropetrographic indices

Modal petrographic analyses carried out on thin slices of rock, using a petrological microscope and point counter, enable quantitative determinations to be made of the volumes of sound and unsound constituents in a rock. A distinction is made between unweathered minerals on the one hand, and the weathering or alteration products including voids and microcracks on the other. The micropetrographic index, indicating a relationship between the percentage of sound and unsound constituents,

$$I_p = \frac{\text{o/o sound constituents}}{\text{o/o unsound constituents}}$$

is a petrological rock quality index related to the degree of weathering of the rock material.

If the modal analysis records separately the different rock constituents, then a micropetrographic fracture index, I_f, recording the percentage of microcracks and voids, can also be determined.

Microfracture indices

Separate microfracture indices have been determined by counting the number of microfractures in a 70 mm traverse of a thin slice of the rock. A total microfracture index I_{ft}, may if necessary be divided into a stained microfracture index I_{fs} and a clean microfracture index I_{fc}.

Geology of the Hingston Down granite quarry

All the specimens analysed have come from a single granite type from the Gunnislake granite of

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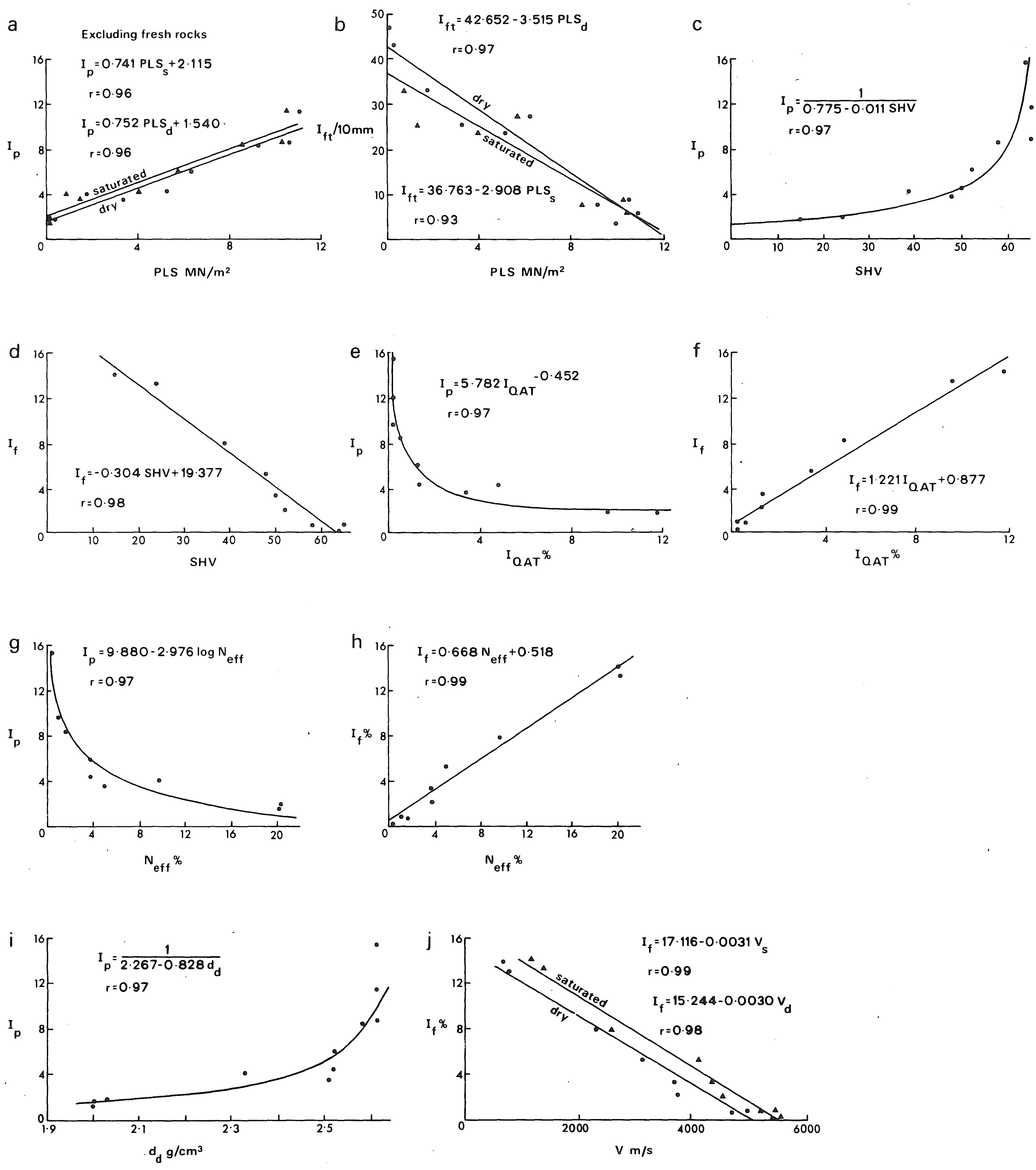

Figure 1.- Relationships between microscopical properties and selected index properties for Hingston Down granite.

a) Micropetrographic index versus dry and saturated point load strength.

b) Total microfracture intensity versus dry and saturated point load strength.

c) Micropetrographic index versus Schmidt hammer value.

d) Microfracture index versus Schmidt hammer value.

e) Micropetrographic index versus quick absorption test index.

f) Microfracture index versus quick absorption test index.

g) Micropetrographic index versus effective porosity.

h) Microfracture index versus effective porosity.

i) Micropetrographic index versus dry bulk density.

j) Microfracture index versus dry and saturated sonic velocity.

S.W. England. The geological setting and the geomorphological aspects of the weathering profile have been described by DEARMAN, BAYNES & IRFAN (1976, fig. 1). Briefly, the granite is a small cupola intruded into Devonian slates between the larger granite masses of Dartmoor and Bodmin Moor. Fresh granite is grey, medium-grained with scattered porphyritic feldspar crystals. Quartz ranges from 33-37 per cent, while altered minerals are less than 6 per cent, microcracks and voids less than 0.5 per cent. The micropetrographic index is greater than 12 in fresh material and is less than 2 in granitic soil from mass weathering grade V.

It is assumed that only remnants of a formerly complete weathering profile are preserved on the present hill. A complete profile covered by "head" deposits is preserved on the flanks of the hill, whereas fresh granite is present at shallow depths beneath the hill crest. Presumably, the weathering products were largely stripped during the Pleistocene from the hill top by solifluction processes to form the head deposits.

Classification or index tests

Standard tests for the classification and characterization of intact rock material have been listed by COTTISS, DOWELL & FRANKLIN (1971). Of those listed, the point load strength (BROCH & FRANKLIN, 1972), Schmidt hammer value (Type N), quick absorption index (HAMROL, 1961), effective porosity, bulk density, and sonic velocity (ILIEV, 1967) are reported here.

Engineering design tests

Material tests in this category (COTTISS *et al,* 1971) are those for the determination of unconfined compressive strength and tangent Young's modulus.

INTERRELATIONSHIPS BETWEEN MICROSCOPICAL PROPERTIES AND SELECTED INDEX PROPERTIES

Detailed results of the determination of micropetrographic and microfracture indices for the seven stages of weathering of Hingston Down granite material have been reported elsewhere (IRFAN & DEARMAN, 1978a, table 2). Similarly the results of the Classification or index tests : point load strength, Schmidt hammer value, quick absorption index, effective porosity, bulk density and sonic velocity will be found in IRFAN & DEARMAN (1978b, table 4).

It is considered that sufficient quantitative data are available to justify determining the best fit functions relating to a variety of microscopical and index properties. Best fit curves frequently have very high degrees of correlation. Results, including functions and correlation coefficients, are given in fig. 1.

Micropetrographic index and point load strength

Point load strength decreases as micropetrographic index decreases with increasing weathering. Fresh granite with no staining has an $I_p > 12$. When all the data, including those from fresh rocks are considered, the relationship is curvilinear and becomes parallel to the Y-axis for I_p values of fresh rock. If I_p values for weathered Hingston Down granite only are plotted, regression analysis gives linear functions with very high degrees of correlation (fig. 1a).

Microfracture index and point load strength

Point load strength decreases as more and more microfractures are formed by weathering. Pores begin to have an influence when the rock is completely stained, and leaching of the alteration products produces more pores in the higher weathering grades. Microscopical studies of fresh rocks reveal very few microcracks, most of which are structural, intragranular, very fine hair-like cracks mainly in quartz. Chemical alteration of biotite and plagioclase, aided by stress relief as denudation continues, is held to be responsible for microfracturing, particularly in the completely stained and the more weathered granite.

Linear relationships give the best fit curves for total microfracture index, I_{ft}, versus dry and saturated point load strengths (fig. 1b). These results confirm that tensile strength is greatly influenced by the microfractures in the rock material.

Micropetrographic index and Schmidt hammer value

Schmidt hammer value decreases as micropetrographic index decreases with increasing weathering (fig. 1c), the relationship being best expressed by an hyperbolic function since I_p for fresh rocks can be up to infinity. Schmidt hammer values obtained from the weathered joint blocks are more indicative of the brokenness of the rock structure since the major mineralogical constituents, apart from plagioclase, are rarely affected by chemical weathering.

Below SHV = 40, the physical state of the rock structure is the major factor in reducing the test values. Above SHV = 40, chemical softening of the plagioclase is the major factor in influencing the test value.

Microfracture index and Schmidt hammer value

A linear regression relationship is the best fit line between these two test parameters (fig. 1d).

Micropetrographic index and quick absorption index

The quick absorption test index is generally indicative of the physical state of the rock material, for example the degree of development of connected pores and microcracks. I_{QAT} increases as micropetrographic index decreases with increasing weathering, and the relationship is best expressed by a power function (fig. 1e).

Microfracture index and quick absorption index

Linear regression gives the best fit line (fig. 1f).

Micropetrographic index and effective porosity

As the rock becomes more weathered, microcracks join together and enlarge and pores are formed in the material due to leaching and removal of secondary products. Effective porosity therefore increases greatly, and the relationship to micropetrographic index is logarithmic (fig. 1g).

Microfracture index and effective porosity

There is a linear relationship between these two parameters (fig. 1h).

Micropetrographic index and bulk density

With high values of micropetrographic index in fresh rock, dry bulk density tends to a constant value (fig. 1i).

Microfracture index and sonic velocity

Relationships for both dry and saturated conditions are linear, with velocity decreasing with increased weathering (fig. 1j).

INTERRELATIONSHIPS BETWEEN MICROSCOPICAL PROPERTIES AND SELECTED ENGINEERING DESIGN PARAMETERS

Unconfined compressive strength and tangent Young's modulus have been determined for the different stages of weathered Hingston Down granite material.

Saturated uniaxial compressive strength and micropetrographic index

Rock strength can be assessed from a modal analysis. In fig. 2a, two curves have been computed; one covering the complete range of weathering effects is curvilinear, the other excluding fresh rocks is a linear relationship with a very high degree of correlation.

Microfracture indices and uniaxial compressive strength

The uniaxial compressive strength is controlled to a great extent by the physical properties of the material (COATES, 1964; SMART, 1970; YOGHISHE & LEONARD, 1972; SIMMONS, TODD & BALDRIDGE, 1975), including mineralogical comosition, texture, degree of interlocking of the grains, voids, microcracks and other planes of weakness.

In fresh granite the boundaries of the interlocking grains are tight, there are a few intragranular, mainly structural microfractures, and hence a high material strength is attained. On weathering, transgranular microfractures and pores start to form, and grain boundaries - particularly quartz-quartz - begin to open. When completely stained rock cores are tested, non-elastic deformation occurs by free movement of the grains to fill voids; highly weathered granite fails axially instead of by cataclasis/cleavage failure in the less weathered and fresh granite.

When micropetrographic fracture index determined by modal analysis is plotted against saturated and dry uniaxial compressive strengths, the best fitting curves (fig. 2b) are logarithmic functions with very high correlation coefficients.

Total microfracture index versus compressive strength is represented by linear regression curves (fig. 2c).

Micropetrographic index and tangent Young's modulus

The relationships are similar to those for unconfined compressive strength, with a logarithmic function for all rocks and a linear function if only weathered rocks are considered (fig. 2d). The simplest relationship for all rocks is $E_t = (0.529\ I_p - 0.09)10^4$ ($r = 0.94$).

The high correlations make it possible to estimate the modulus of elasticity from modal micropetrological analysis, from which a micropetrographic index quantifies the state of the rock material.

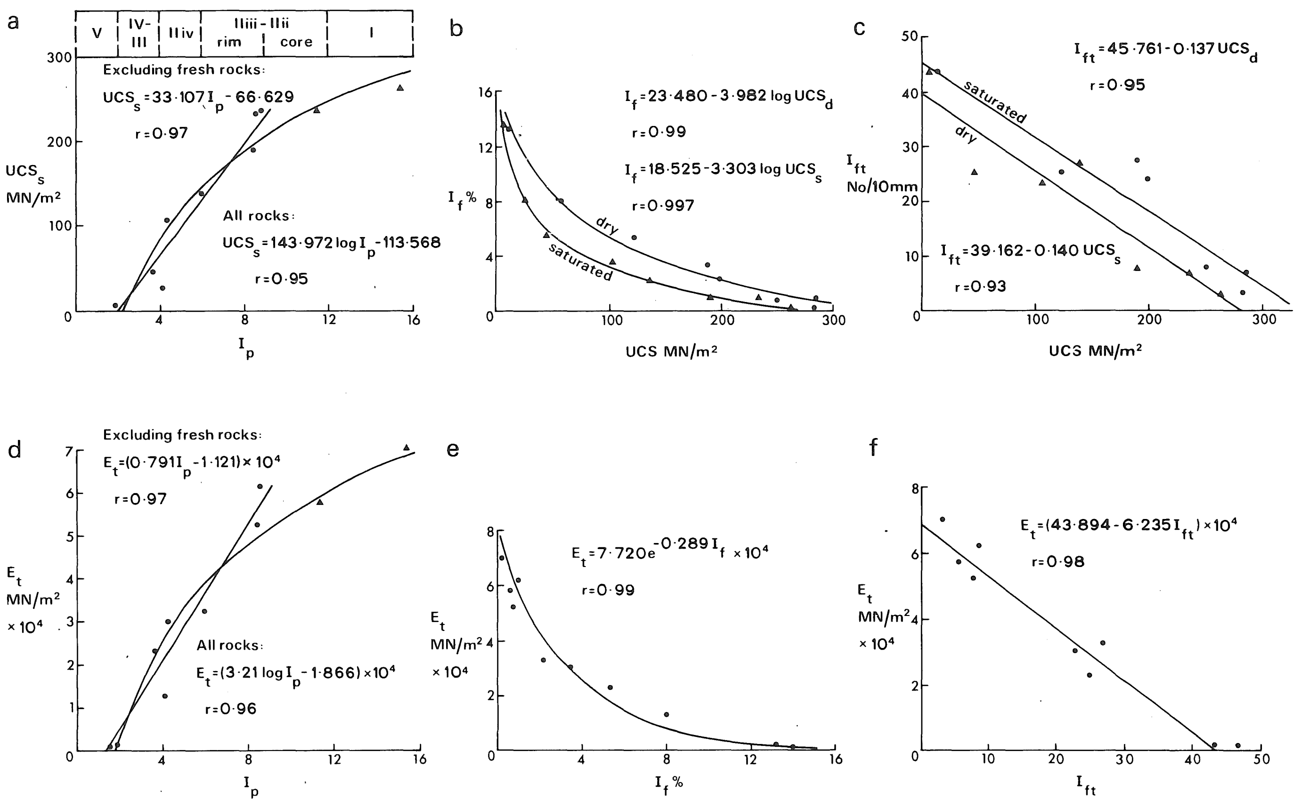

Figure 2.- Relationship between microscopical properties and selected engineering design parameters for Hingston Down granite

a) Saturated uniaxial compressive strength versu micropetrographic index.

b) Micropetrographic index versus dry and saturated uniaxial compressive strength.

c) Total microfracture index versus dry and saturated uniaxial compressive strength.

d) Tangent Young's modulus versus micropetrographic index.

e) Tangent Young's modulus versus microfracture index.

f) Tangent Young's modulus versus total fracture index.

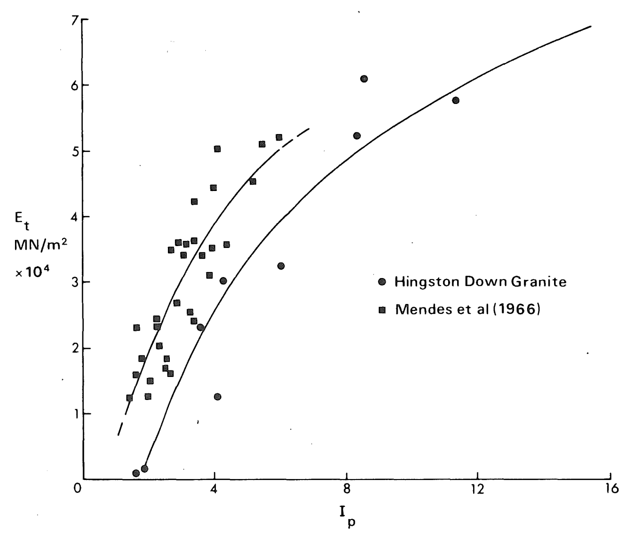

Figure 3.- A comparison of correlations between the results obtained for tangent Young's modulus versus micropetrographic index for granite by Mendes et al., 1966 and for Hingston Down granite.

Microfracture index and tangent Young's modulus

An exponential relationship exists between the modal analysis microfracture index and Young's modulus (fig. 2e) whereas it is linear between total microfracture index and Young's modulus (fig. 2f).

DISCUSSION AND CONCLUSIONS

The various stages of weathering of rock material in the granite of Hington Down have been characterized in terms of micropetrographic indices and experimentally determined values of classification and engineering design tests.

Completely weathered granite exposed in the quarry has a petrographic index of 1.5, indicating that chemical decomposition is not complete. For a quartz content of approximately 30 per cent, the I_p value should be 0.4 if all minerals other than quartz have been altered to clay minerals and voids.

Point load strength is affected by the amount of secondary minerals in the rock, but more particularly by the development of microcracks. There is a linear relationship between micropetrographic index and point load strength at any moisture content. High correlations between uniaxial compressive strength and micropetrographic index show that rock strength can be assessed by a quantitative petrographic study.

Modulus of elasticity can similarly be estimated and correlations of I_p v E_t have been published for granite by MENDES, AIRES-BARROS & RODRIGUES (1966). Their graph is reproduced as Fig. 3, together with the Hingston Down results. I_p values given by MENDES *et al.* are lower for particular E_t values than the Cornish granite. This could be due to more intense chemical alteration, but they do not state how altered and unaltered minerals were recognised microscopically; textural factors, including grain size and degree of interlocking of grains, could also account for the difference.

p The quick absorption index, I_{QAT}, indicative of the physical state of the rock material, is greatly influenced by the amount and type of microfractures and by the character of the infilling material. Determination of the micropetrographic fracture index, I_f, gives a close approximation to the volume of pores determined by the absorption test, but for the least weathered rocks I_f values are greater than corresponding I_{QAT} values, probably because many of the pores and microcracks are unconnected, but there is an element of statistical exaggeration (CHAYES, 1966) in the microscopic method.

The following conclusions may be drawn :

(i) for weathered Hingston Down granite, with high correlation coefficients between micropetrographic indices and index and engineering properties, it is possible to predict reliable engineering properties from microscopic study of the rock material.

(ii) micropetrographical methods are advantageous because they enable the behaviour of rock material to be assessed after processing for use, and in use (cf. WEINERT 1968).

(iii) weathering grades can be evaluated quantitatively in terms of the micropetrographical indices of material types involved.

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