

PHYSICAL AND CHEMICAL PROPERTIES OF DECOMPOSED GRANITE SOIL GRAINS

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ABSTRACT

The decomposed granite soils known locally as "Masado" are regarded as a special type of soils, because the soil grains are relatively unstable under mechanical or chemical actions. The properties of individual soil grains, which are important for the engineering purposes are examined by means of physical, chemical and mineralogical analyses.

From the results of these analyses, it is concluded that the specific gravity of feldspar and the content of coloured minerals are the important factors to determine engineering properties of the soils.

1. INTRODUCTION

In recent years, the decomposed granite soils have been studied for the engineering purposes. They are known locally as "Masado" and regarded as a special type of soils. Even if they appear to be sandy soils at a glance, they may in some cases behave like cohesive soils. The granite soils, subjected severely to weathering, are relatively sensitive to mechanical or chemical actions and unstable under these actions. In addition, their mineral compositions vary to a greater extent than those of sandy soils usually found in alluvial deposits; they are composed mainly of minerals such as quartz, feldspar and coloured minerals in which the secondary clay minerals are present to some extent.

In addition to the generally accepted factors such as grain size, grain shape, porosity, water content and soil structure, the mineral composition and alteration of the granite soils become important factors for the engineering purposes.

The authors previously discussed the mineral compositions of the soils and their influence on the engineering properties. In this paper, they attempt to examine chiefly the alteration of the granite soils in order to understand rationally their engineering properties. On the basis of these studies, a new classification is proposed.

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2. COMPOSITION OF PRIMARY MINERALS

The decomposed granite soils contain various species of clay minerals which are identified only by means of an X-ray diffractor meter and a few other instruments. Although these species and the amount of clay minerals are an efficient key in determining the degree of weathering, it is difficult at present to determine it quantitatively. Therefore, for engineering purposes, it is rather convenient to express the clay minerals quantitatively as a part of the altered primary minerals. Mineralogical and petrographical descriptions have been made by geologists. However, their published results are limited mostly to fresh rocks. Therefore, the authors have tried to analyse the granite soils collected from several regions by the following conventional method.

First, the soil samples were dried in an oven at 110°C and then crushed into fine particles of 0.07 to 0.4 mm in size. After rinsed with methyl alcohol, coloured minerals were separated from quartz and feldspar with a magnetic separator. The remaining quartz and feldspar were separated from each other with the use of heavy liquid tetrabromoethane. Since the specific gravity of weathered feldspar contained in the soils is generally less than that of quartz, it is easy to separate one from the other. The apparatus used is shown in Figs. 2a and 2b and the results of the analyses are shown in Fig. 1. The samples were collected from Ikoma, Hieizan, Hiroshima, Okayama and Rokko granite regions.

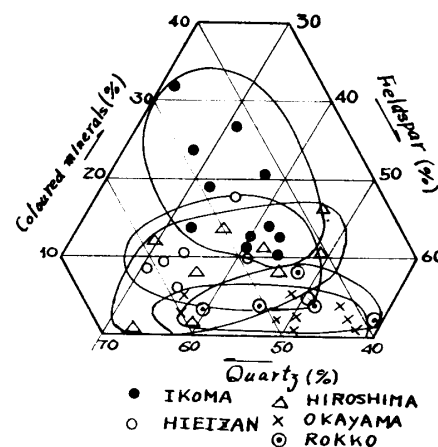


Fig. 1

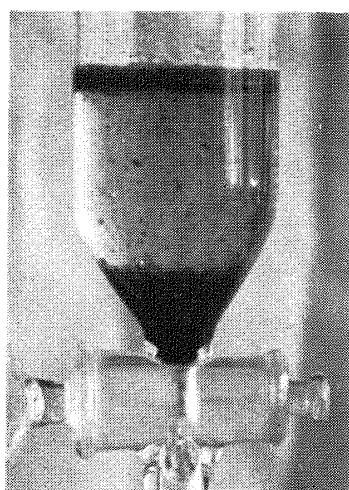


Fig.-2a Mineral Separation

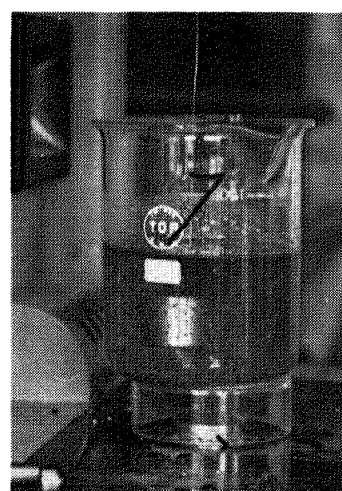


Fig.-2b Measurement of Specific Gravity of Feldspar

The Ikoma granite belonging to the Ryoke granites contains much more coloured minerals than the others which belong to the Hiroshima granites. It is found in the Ikoma granite that there are more abundant coloured minerals and more variation in mineral compositions. These facts suggest that the nature of the parent rock also affects the mineral composition of the soils considerably.

3. PHYSICAL PROPERTIES OF THE SOIL GRAINS

3.1 Specific Gravity of Feldspar: The most important and fundamental factors affecting the engineering properties are presumed to be the characteristics of feldspar and the amount of the coloured minerals. Above all, feldspar is present abundantly in the soils, so its investigation seems to be more significant. Therefore the authors attempted first to examine the specific gravity of feldspar grains. It was determined indirectly by using tetrabromoethane. In this procedure, the liquid was diluted by adding methyl alcohol gradually until the feldspar grains were dispersed in the liquid as uniformly as possible. By this method, the specific gravity of feldspar grains can be determined without removing them from the liquid.

In this process accuracy is required. A weight hanging from a balance by a thin platinum wire was immersed in the liquid, as shown in Fig. 2b. With the weight measured in the liquid as well as in water and in air, the specific gravity was calculated by means of the following formula:

$$G_{sf} = \frac{W_0 - W_l}{W_0 - W_w} \dots\dots\dots(1)$$

Table 1.

Field properties	Point No.	Gsp.	Gsf.
Soft rock $\longleftrightarrow$ cutting slope Weathered soils	1	2.572	2.384
	2	2.646	2.486
	3	2.645	2.516
	4	2.647	2.512
	5	2.624	2.520
	6	2.652	2.522
	7	2.649	2.550
	8	2.648	2.562
	9	2.651	2.585

Gsp: Specific gravity of all grains by pycnometer method.

Gsf: Specific gravity of feldspar by heavy liquid.

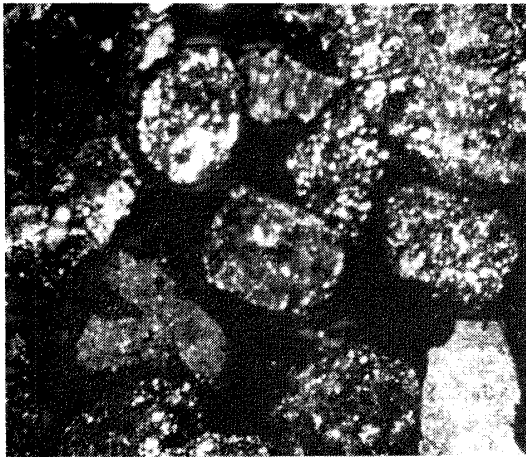


Fig.-3a Gsf 2.25

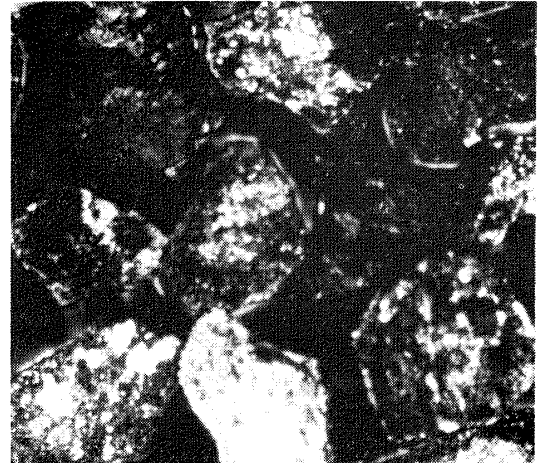


Fig.-3b Gsf 2.47

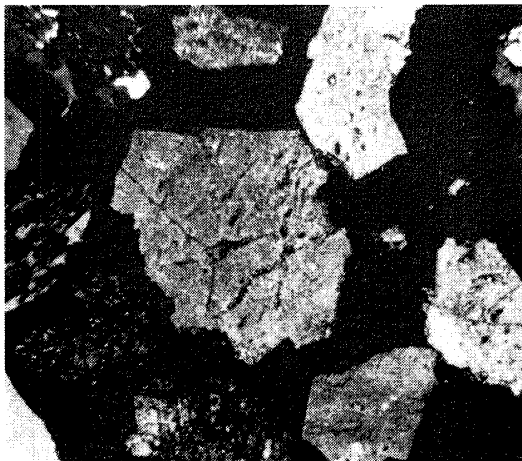


Fig.-3c Gsf 2.53

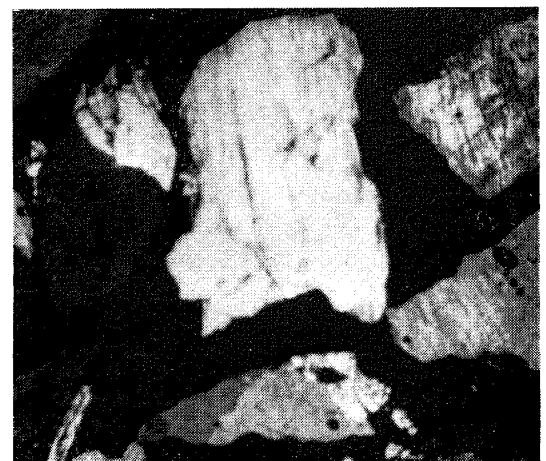


Fig.-3d Gsf 2.56



Fig.-3e Gsf 2.58

Where, G_{sf} : Mean specific gravity of feldspar grains;

W_0 : Weight of the weight in air;

W_w : Weight of the weight in water;

W_l : Weight of the weight in the liquid.

The results are shown in Table 1. In comparison, the specific gravity of the soil grains obtained by the pycnometer method is also shown in the table. The specific gravity of the soil grains varies from 2.57 to 2.65, and G_{sf} ranges from 2.38 to 2.58, and the variation of the latter is larger than that of the former. Therefore, G_{sf} can be regarded as a more efficient criterion for determining the degree of alteration. Low values of G_{sf} means that various ions such as K, Na and Ca are leached out from crystal lattice during weathering.

Figs. 3a to 3e show examples of the grains observed in thin sections through a polarized microscope. It is evident from these that the microscopic pore spaces or cracks increase gradually with the value of G_{sf} decreasing. If these voids found within the grains are completely closed to infiltration of liquid, it should be expected that G_{sf} becomes larger as the grains are crushed.

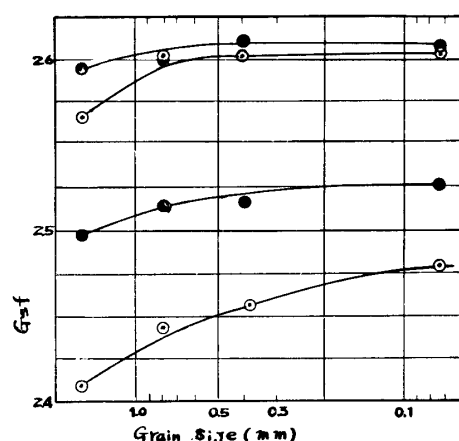


Fig. 4. Variation of G_{sf} with Crushing.

Therefore, the grains were crushed and grouped into four successive grades ranging from 1.6 to 0.074 mm in size, and G_{sf} of the samples from each of these grades were determined. Fig. 4 shows the variation of G_{sf} with the degree of crushing of the grains. Furthermore, G_{sf} of the grains having a smaller initial value increases more than those having a larger initial value. As the crushing progresses, however, it reaches a constant value which is regarded here as the specific gravity without the influence of pores. The existence of the pores seems to be significant. However, the reduction

of G_{sf} is considered to depend not only on the microscopic pores but also on the crystallographical defects within the grains.

3.2 Relation between the Specific Gravity of Feldspar and Other Properties: Since reduction of G_{sf} means internal alteration of crystal grains, it must also have a certain bearing on the grain strength. The orthoclase grains, 1.6 mm in size and having a G_{sf} of 2.3 to 2.6, were compressed with a steel rod, 3 mm in diameter to obtain compressive strengths. According

to the results as shown in Fig. 5, the compressive strength of the grains decreases rapidly with G_{sf} decreasing down to the value of 2.45, below which it becomes extremely small. The strength corresponding to the range of G_{sf} from 2.45 to 2.6 varies almost linearly with G_{sf} . Since crystal grains are anisotropic to mechanical forces, the values obtained are somewhat scattered.

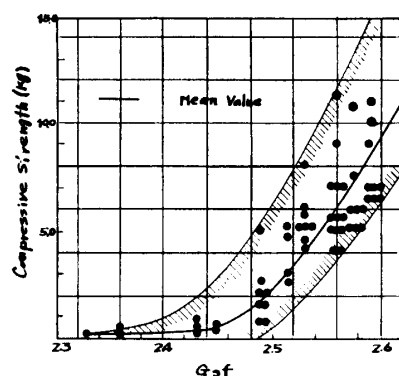


Fig. 5. Compressive Strength of Feldspar Grains

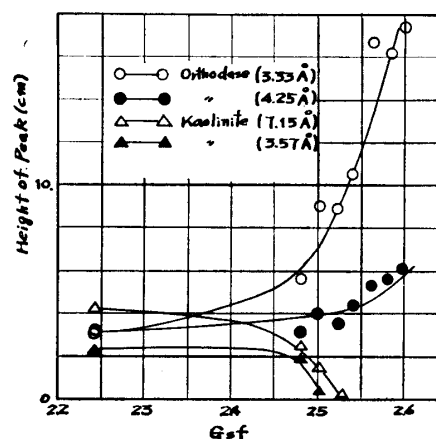


Fig. 6. X-ray Diffraction Strength

On the other hand, in order to examine the crystallinity of the grains, X-ray diffraction analyses were performed on samples of the grains which were crushed into fine particles smaller than 0.03 mm in size. According to the results shown in Fig. 6, it is found that the major constituent mineral is orthoclase and the X-ray diffraction strength decreases with the reduction of G_{sf} from 2.60 to 2.45. In the region below 2.45, secondary minerals such as kaolinite become dominant. In order to express the X-ray diffraction strength of d -spacing 3.33 Å and 4.25 Å of orthoclase and 7.15 Å and 3.57 Å of kaolinite, the values of the height of peak recorded on the spectrograph are plotted in Fig. 6.

The compressive strength of the grains was found to be fairly well related to the X-ray diffraction strength. The higher is the peak recorded, the higher is the crystallinity. Decrease in the peak height indicates internal alterations such as lattice defects and crystal deformations which have taken place in the process of weathering.

Next, in order to examine the internal bonding force of the grains which is supposed to be related to the compressive strength, the heat of solution of grains in hydrofluoric acid was measured.

The bonding energy of a crystal grain is generally expressed as the amount of heat reduction from a standard condition in which the crystal is able to exist in rarefield gas. The crystal was brought into the solid state of lower energy level from the liquid state of higher energy level during the cooling

process, and the larger is the difference from the standard condition, the more stable is the condition (Sudō 1964).

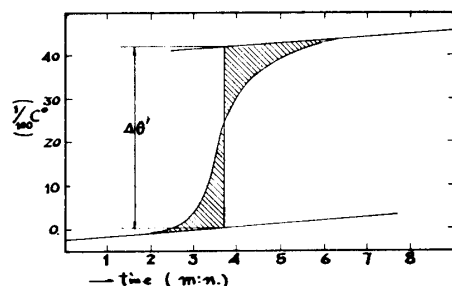


Fig. 7. Relation between Temperature Rise and Time

After the sample was mixed with the liquid, the progressive rise in temperature was recorded at regular intervals. An example of these recordings is shown in Fig. 7. From these data, the heat of solution ΔH , is calculated by means of the following formula:

$$\Delta H = \frac{C \cdot \Delta\theta'}{m} \dots\dots\dots (2)$$

Where, ΔH : heat of solution, (cals/g);

C : heat equivalent of the apparatus (Cals/ $^{\circ}C$);

$\Delta\theta'$: corrected rise in temperature ($^{\circ}C$);

m : weight of the samples (g).

The results shown in Fig. 8 indicate that the heat of solution varies linearly with G_{sf} in the range of 500 to 600 cals/g, and does not correspond well with the compressive strength. Additional tests were carried out on the samples having an approximate grain size of 1.6 mm under the same conditions as mentioned above. According to the results, as shown by the lower curve in Fig. 8, ΔH is inclined to decrease as G_{sf} increases. The difference D between the values of heat of solution of the powder and the granular samples is relatively well related to the compressive strength of the grains as shown in Fig. 9. From another point of view, D is related to the mechanical energy required to crush the grains from 1.60 mm to 0.03 mm in size. It is also suggested that D represents a part of the relative bonding energy of the grains. Therefore, the strength of the grains depends not only on the substantial bonding force but rather greatly on the inherent cracks

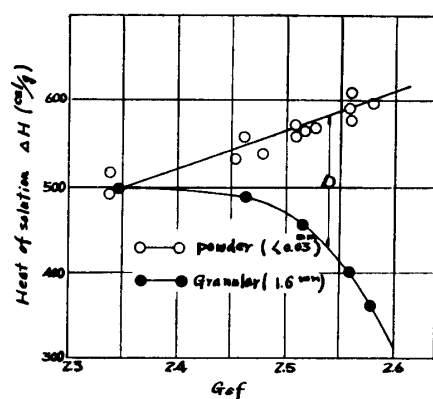


Fig. 8. Heat of Solution in Hydrofluoric Acid

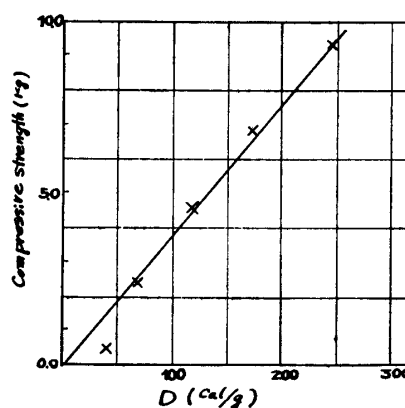


Fig. 9. Relation between Compressive Strength and D

or voids found within the individual grains as it is well known in the case of rock samples. Furthermore, D becomes an index of stability of the grains for the chemical alteration. When a given soil is found to have a value of G_{sf} less than 2.45, even if it is classified as a sandy soil, it should be regarded as an aggregate of finer particles.

4. CHEMICAL PROPERTIES

Those discussed in the foregoing section may also be referred to as chemical properties. It is understood that the polymerization of atoms at the very surface of weathered feldspar grains is completely broken and they are scarcely saturated with cations (George, W. 1967). Therefore, in order to find out the difference of chemical properties between the surface and the internal parts of the grains, granular and powder samples, each weighing 1.5 gms were mixed with 50 cc of water completely free from CO_2 and other ions. After about one hour of stirring, the pH value of the suspension was measured with an electrode-type pH meter.

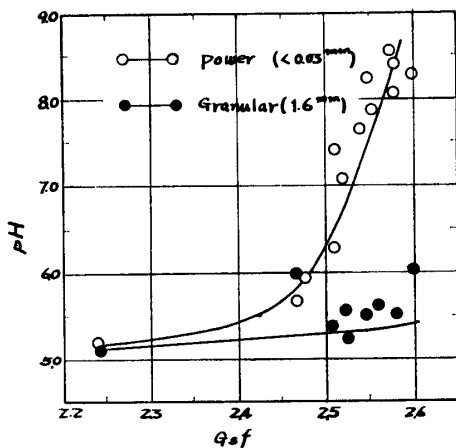


Fig. 10. pH of the Suspension

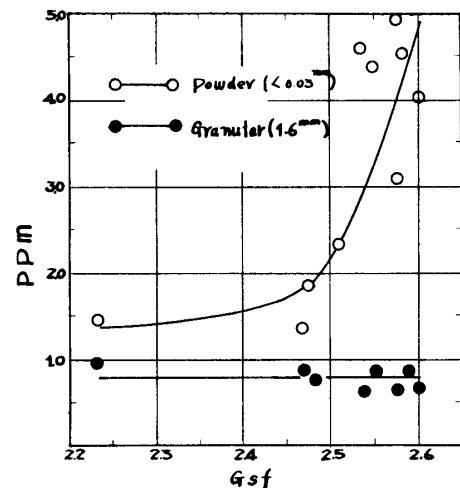
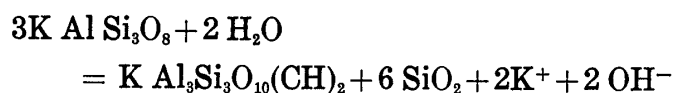


Fig. 11. Content of K^+ ion in filtrated water

The results in Fig. 10 show that pH of the powder samples changes markedly with G_{sf} , whereas that of the granular samples remains almost unchanged throughout the range of G_{sf} . Although the difference between the two cases may be due partly to the difference of the surface areas, these facts show that the chemical properties of the surface differ considerably from those of the internal parts caused by weathering. The pH value of the powder suspension is also well correlated with the K^+ ions contained in filtrated water, as shown in Fig. 11. The exchange of ions may take place in accordance with the following formula reported by R. H. Garrels (Garrels and Howard, 1967).



In this reaction H^+ ions are exchanged with K^+ ions.

The grains having a smaller value of G_{sf} show a lower and acid-side value of pH, because the constituent ions such as K^+ , Na^+ and Ca^{++} have been leached out leaving the surface unsaturated. Accordingly the degree of weathering of soils can be estimated by measuring the pH value of a suspension of crushed feldspar. However, the conditions during measurements should be strictly controlled.

5. A PROPOSAL FOR QUALITATIVE CLASSIFICATION OF THE SOILS

In classifying the soils for engineering purposes, two items are considered to be important based on the results of these analyses and the studies already made (Matsuo and Nishida, 1966). One is the content of coloured minerals and the other is the specific gravity of feldspar. The former is considered to be an important factor because it is related to properties such as larger swelling, shrinkage and higher compressibility as already well recognized. On the other hand, the latter is the most essential factor relating to grain strength. The characteristic phenomenon of over compaction can be examined by this factor. There are various methods to determine the degree of

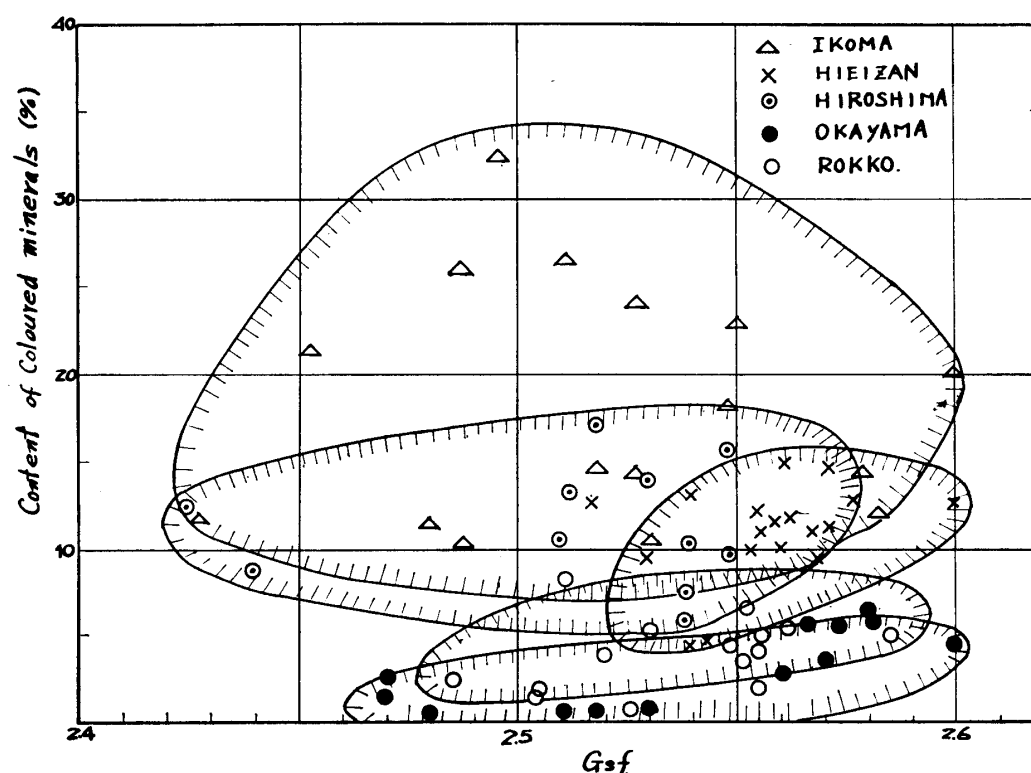


Fig. 12. Qualitative Classification

weathering.

Above all, the methods for determining field density, elastic velocity and crystallinity of mica (Magee, 1960) can be adopted for practical use. However, the first two are restricted to field survey, whereas the third is more complicated in practical application. In Fig. 12, samples collected from different localities are represented in terms of the relationship between G_{sf} and the content of coloured minerals. Although the results are modified to some extent, G_{sf} generally ranges from 2.4 to 2.6. Soils having a G_{sf} over 2.6 are regarded as soft rocks and they have an elastic wave velocity of 1000 to 1500 m/sec according to field observations. The lower limit of G_{sf} differs according to the sampling locality and geohistorical and topographical conditions.

6. SUMMARY AND CONCLUSIONS

The results of the analyses described above are summarized as follows:

- 1) Specific gravity of feldspar can be regarded as an efficient criterion in determining the degree of weathering.
- 2) The reduction of G_{sf} which takes place during weathering is related to the compressive strength and X-ray diffraction strength of the grains.
- 3) Based on the study on the heat of solution of the feldspar grains in hydrofluoric acid, it is concluded that the strength of the grains depends not only on the bonding force but greatly on the inherent cracks or voids within the individual grains.
- 4) The mineral composition of the soils differs considerably depending upon the localities and determines the engineering properties. The more the coloured minerals, the lower become the dry density and the strength in certain compaction works.

Based on these facts, it is clear that the specific gravity of feldspar and the content of coloured minerals are the important factors in determining the engineering properties of the decomposed granite soils. These factors should be examined together with the well-recognized factors such as grain size, porosity, water content, and soil structure.

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