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Weathering on granitic rocks in Imagane, Hokkaido

Hiroshi Shirahata and Tetsuo Suzuki

Abstract

Weathering effects on granitic rocks have been investigated. Relatively small acid plutonic bodies, which are distributed in Imagane, a district in southwestern Hokkaido, are hornblende biotite granodiorites, which are considered to be formed in the Cretaceous time. Field observations have disclosed that the weathering feature and processes of the granodiorites have been affected markedly by water. Especially, Masa was frequently found around the junctions of water streams. The degrees of weathering on a profile of a rock are divided into five macroscopic classes : fresh, slight weathering, moderate weathering, high weathering and Masa. Following the field observations, the mineralogical and geochemical changes developed on weathering profiles were investigated. The relative mineral stabilities, from the least stable to the most, are : plagioclase, biotite and hornblende, K-feldspar and quartz as expected. A gradual depletion in calsium and sodium, steep depletion in magnesium and dispersive variation in potassium during weathering are presented diagrammatically. A new weathering index, mole $(CaO + Na_2O + K_2O)$/mole Al_2O_3, is proposed. It is a good indicator of chemical weathering just as Reiche's WPI. Both indices, moreover, were directly related with bulk density of the granodiorites studied.

Introduction

The granitic rocks distributed in particular parts of southwestern Hokkaido have been studied petrographically and petrochemically by Suzuki and Nemoto (1935), Suzuki (1957), Sato and Shirahata (1965), and Tonosaki (1967). However, unfortunately, no systematic investigations on the weathering of them have been promoted.

Landslides triggered by heavy rainfalls have occurred frequently in weathered granitic regions (Koide, 1968a) : for instance, in July 1964 the eastern part of Shimane Prefecture was damaged heavily by numerous landslides. It is worthy to note that these areas are granitic regions consisted mainly of rocks which have been completely or almost transformed to Masa (Koide, 1968b ; Khono *et al.*, 1968). Rock weathering must be one of the essential factors in landslide disasters, and also weathering reactions would be considered to reflect the changes of chemical and mineralogical compositions and the changes in physical properties. Therefore studies on the weathering of granitic rocks may be of importance to the geologists as well as to the civil engineers.

Geochemical and mineralogical researches of weathering on granitic rocks in the southwestern part of Hokkaido were started several years ago. Some mineralogical alterations and chemical variations during weathering processes in the granodiorites in Imagane district are presented in the following sections.

Outline of geology

Imagane district situated on the eastern part of Setana-gun, roughly central area of

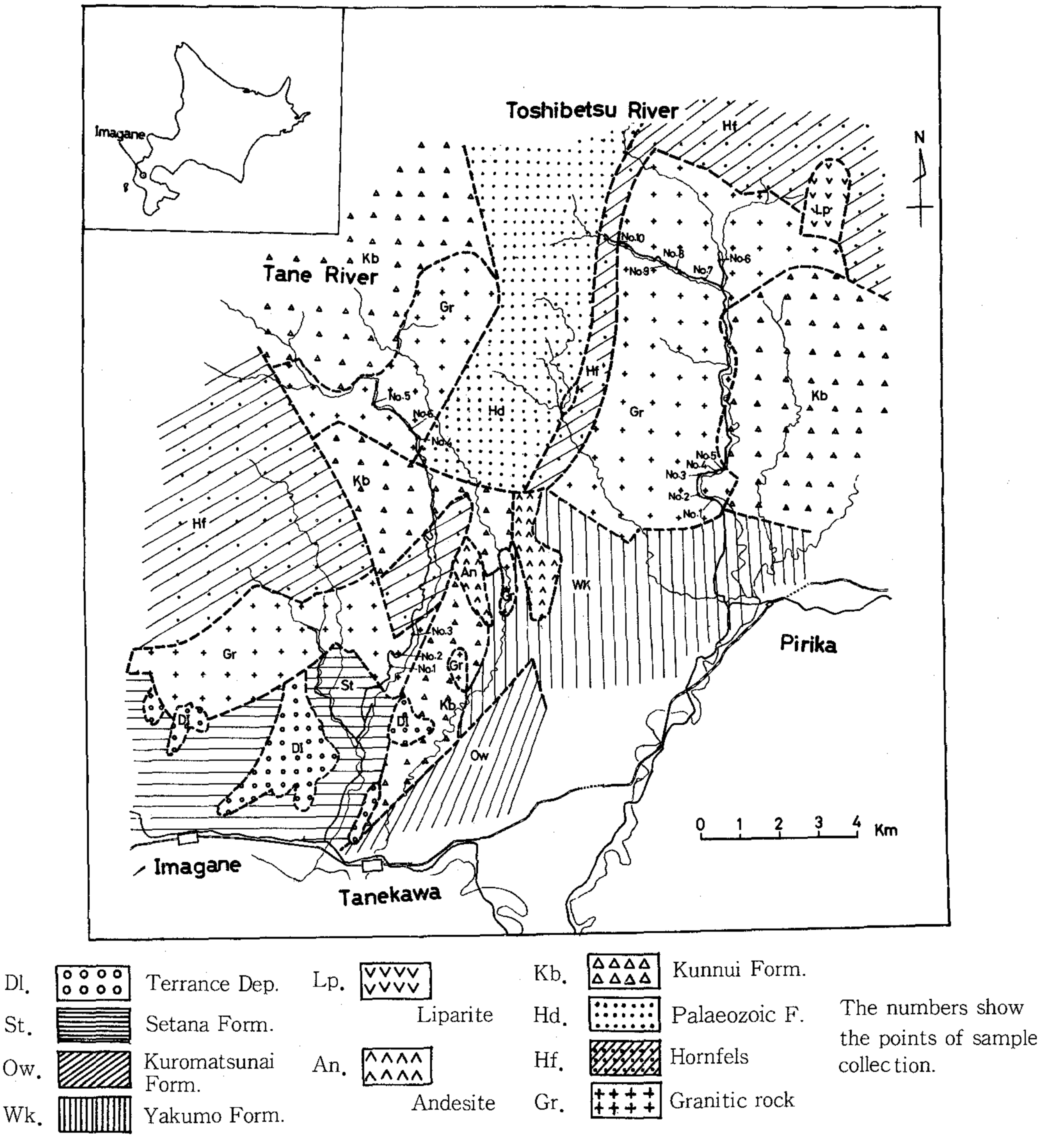
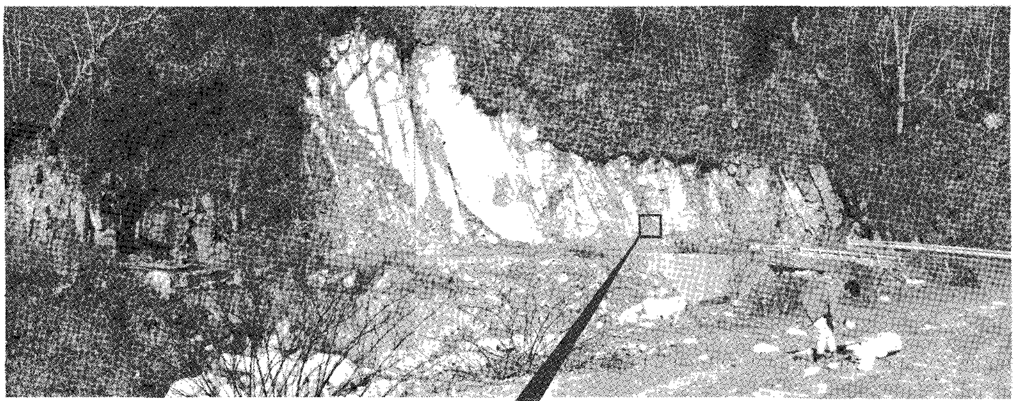


Fig. 1 Geological map of Imagane district

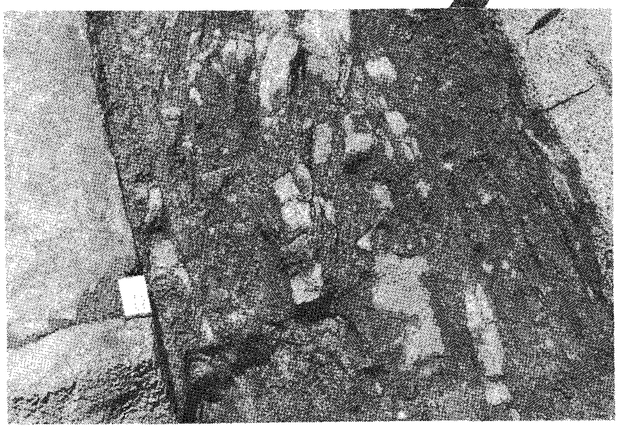
southwestern Hokkaido, is noted of the granitic intrusions. These granitic rocks there are the basements of Neogene Tertiary systems, which are divided into Kun-nui, Yakumo, Kuromatsunai and Setana formations in ascending order (Matsui *et al*., 1955). Three principal granitic masses are located in north-western part of Imagane : the northern side of Imagane, the upper part of the Toshibetsu river and a part between them, as shown in a geological map (Fig.1). The granitic masses intrude discordantly into the pre-Tertiary

Plate A



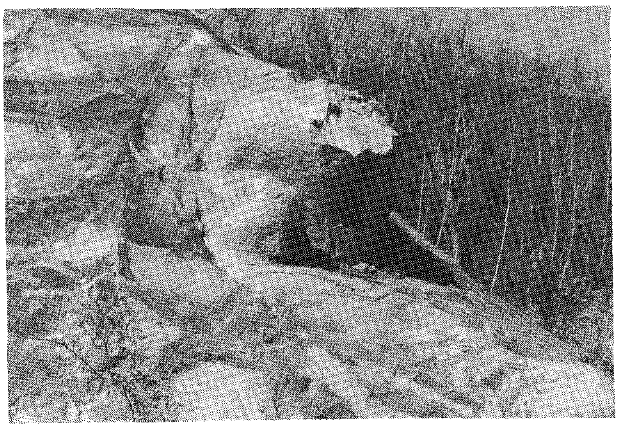
Outcrop showing the granitic rocks from fresh to weathered part.

Plate A



The clayey zone found in the fresh host rock.

Plate B



Outcrop showing Masa zone.

The large rounded blocks are the corestones escaped weathering.

formations that are composed of dominant black slate and gray coloured greywacke accompanied with chert and limestone, and are also covered unconformably with Neogene deposits. Pre-Tertiary formations have been considered as the Palaeozoic (Matsui *et al.*, 1955). They have been widely affected by metamorphism and contact aureoles in particular are observed around the granitic bodies. The typical location of the contact aureole was found at the granitic body of the northern side of Imagane. Lithology of each plutonic rock shows a distinct difference in mineralogical and petrochemical compositions, and besides that essential mineral grains in marginal parts of every mass become finer. Since the report of Kawano and Ueda (1966), acid plutonic activity in Imagane district has been considered to be an event in the late stage of the lower Cretaceous.

Field description and collection

In order to study the weathering of granitic rocks, as given in a map, the samples were collected from twelve weathering profiles, in each of which there appeared clearly a series of weathering degree from fresh to Masa. These profiles observed on the outcrops would certainly be indicated *in situ* alteration. Samplings were made at roadcuts and recent excavations, and also fresh and weathered rocks were collected according to the following scale of weathering :

1) Fresh ; A rock specimen shows no macroscopic change in constituent minerals and stands against hittings with a hammer.

2) Slight weathering ; The rock still keeps its solidity, but a few reddish brown spots are found on its surface.

3) Moderate weathering ; The rock is easily broken by 4 or 5 hittings with a rock hammer. It contains oxidized iron and plagioclase, a major mineral in granitic rocks, becomes tarnished.

4) High weathering ; The rock's surface is nearly covered with iron rust, and appears porous. The rock can be broken by only one hammering.

5) Masa ; The rock can be broken apart with hands but the original granite fabric remains, which suggests that it is *in situ* weathering.

Although, roughly speaking, the degree of weathering increases gradually from fresh to Masa, a remarkable feature of the weathering degrees is that they do not always occur in a regular order. Photoplate A. shows a discordant weathering appearance. It appeared that a gritty clay zone in the middle of the picture is the result of violent weathering along a joint or fracture in the fresh granitic block. The boundary between unweathered host rock and clayey zone is quite sharp, in spite of the presence of watery zone. It is observed generally that the granitic rocks around the junctions of water streams are altered strongly, and frequently becomes to Masa. This most weathered part, Masa zone, consists mainly of crossed clay bands of several centimeters in thickness and friable sands of quartz, feldspars and mica in between them ; the former represent joints and fractures in the past. Comparatively fresh corestones are found frequently in these Masa (Photo B.). The weathering feature indicate that the original structure has been well preserved in Masa.

Table 1 Chemical analyses of frseh and weathered rocks

	I						
	75062208	75062212	75062210	75062213	75062211	75062101	75062105
SiO_2	65.89	65.54	65.90	65.21	68.00	61.74	62.43
TiO_2	0.66	0.63	0.62	0.60	0.45	0.77	0.73
Al_2O_3	13.97	15.25	14.75	15.32	14.02	16.18	15.88
Fe_2O_3	1.32	1.36	1.44	1.73	2.87	1.26	1.56
FeO	3.85	3.42	3.33	3.02	0.82	4.77	4.44
MnO	0.11	0.11	0.10	0.10	0.11	0.11	0.11
MgO	2.38	2.02	2.06	2.01	1.76	3.04	3.00
CaO	4.35	4.09	4.04	3.66	2.56	5.34	5.27
Na_2O	3.05	2.80	2.63	2.35	2.07	2.65	2.66
K_2O	2.90	3.18	3.58	3.41	2.56	2.76	2.35
P_2O_5	0.37	0.16	0.21	0.11	0.13	0.12	0.17
H_2O+	1.18	1.25	1.03	1.52	2.19	1.27	1.31
H_2O-	0.18	0.29	0.28	0.64	2.62	0.23	0.38
Total	100.21	100.10	99.97	99.68	100.16	100.24	100.29

II			III				
75062102	75062103	75062104	75062119	75062122	75062123	75062120	75062121
61.92	61.80	61.10	68.80	69.25	69.53	69.54	70.02
0.76	0.69	0.70	0.36	0.32	0.30	0.30	0.28
15.53	15.75	15.26	15.23	15.10	15.25	15.14	15.11
1.60	2.63	3.66	0.49	0.84	1.56	2.45	2.03
4.66	3.55	2.47	2.85	2.55	1.62	0.86	0.76
0.11	0.10	0.08	0.10	0.09	0.07	0.05	0.05
3.14	3.07	2.97	1.13	1.10	0.96	0.85	0.79
4.99	4.60	3.88	3.19	3.13	2.62	2.34	2.33
2.58	2.45	2.16	3.18	3.20	3.10	3.00	2.99
2.90	2.60	2.58	3.76	3.39	3.48	3.93	3.78
0.14	0.11	0.12	0.09	0.09	0.09	0.08	0.08
1.42	1.83	2.62	0.87	0.84	1.15	1.19	1.21
0.40	0.82	1.73	0.15	0.21	0.34	0.46	0.59
100.15	100.00	99.33	100.20	100.11	100.07	100.19	100.02

I : Hornblende biotite granodiorite
5.4km northern part of Tanekawa
75062208 fresh
75062212 slight weathering
75062210 moderate weathering
75062213 high weathering
75062211 Masa

II : Hornblende biotite granodiorite
3.2km northern part of Pirika
(marginal part of the granitic mass)
75062101 fresh
75062105 slight weathering
75062102 moderate weathering
75062103 high weathering
75062104 Masa

III : Hornblende biotite granodiorite
3.7km northern part of Pirika
75062119 fresh
75062122 slight weathering
75062123 moderate weathering
75062120 high weathering
75062121 Masa

Petrography

In general, granitic bodies in Imagane district are light gray, medium-grained hornblende biotite granodiorites. Their texture are hypidiomorphic granular. In a thin section of the fresh sample plagioclase is subhedral, usually polysynthetically twinned and at the same time weakly zoned crystals, while potash feldspars are wholly allotridiomorphic and fill the interspaces between the surrounding minerals ; there is only a trace of kaoline in potash feldspar and also a small amount of sericite is found here and there in plagioclase. The amount of hornblende contained in granodiorites found along the Toshibetsu river, the northern side of Pirika, is slightly smaller than those in granitic bodies of other parts of Imagane. Particularly, this modal composition in a sample from Chaya-gawa is very small (Sato and Shirahata, 1965). The biotite, a major ferromagnesian mineral present, is of a subhedral, sometimes idiomorphic slender shape. Even in a sample of relatively fresh rock, it is often altered to the chlorite along cleavage planes and fractures, and is somewhat stained with iron oxides. In the early phases of weathering sequence, sericitization and kaolinization occur on some parts of the plagioclase surface. These reactions take place initially around calcic cores, cleavages and cracks. A little amount of kaoline is observed on K-feldspar surface and a slightly larger amount of chlorite is produced on the surfaces of both hornblende and biotite. The next stage of alteration is characterized by plagioclase with prominent sericite and kaoline, potash feldspar showing gradational enrichment of kaoline, and ferromagnesians with a considerable amount of chlorite and iron oxides. In the late and final stages of weathering, almost all plagioclase is transformed to aggregations dominantly of kaoline clay and micaceous minerals. A great deal of kaoline clay and some micaceous minerals are found in K-feldspar. Hornblende and biotite are converted nearly perfectly to chlorite and other clay minerals, therefore they sometimes show pseudomorph and/or completely irregular appearance in shapes under the microscope. Iron-oxide network or veinlet derived from the dissolution of mafic minerals are spread on the highly weathered rock surfaces. On the other hand, quartz, being the most resistant mineral, has no considerable changes during weathering, though in the final weathering phase it becomes smaller and fragmental crystal. A trace of calcite was developed in the thin section of the granodiorite from the upper side of the Toshibetsu river. It is not clear whether this is a product of the weathering or the hydrothermal alteration. Relative mineral stabilities in granodiorite found on the basis of microscopic observations, from least to most stable, are : plagioclase, biotite and hornblende, potash feldspar, and quartz. This stability order agrees well with the previous investigations by Harris and Adams (1966), and Jin-nai (1973).

Chemical variation

Sample of various weathering stages, 1-2Kg each, were crushed to less than 60 mesh in size, and a quarter of each was grinded finely in a agate motor and analyzed chemically by the ordinary wet method except for calsium, magnesium, sodium and potassium (Shirahata, 1972). Alkaline and alkaline earth metals were determined by the atomic absorption spectrophotometry (Terashima, 1970) using a spectrophotometer Hitachi model 508. The results are

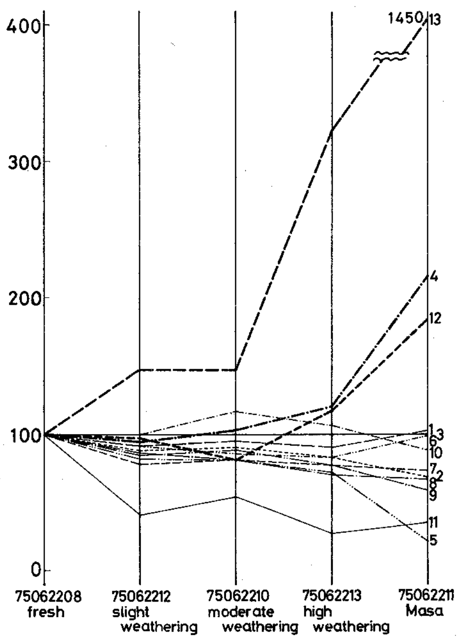


Fig. 2 Chemical variations during weathering

1:SiO_2 2:TiO_2 3:Al_2O_3 4:Fe_2O_3 5:FeO 6:MnO 7:MgO 8:CaO 9:Na_2O 10:K_2O 11:P_2O_5 12:H_2O+ 13:H_2O-

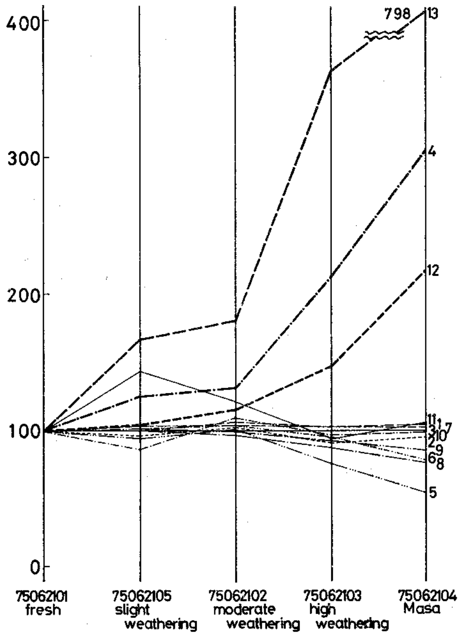


Fig. 3 Chemical variations during weathering

1:SiO_2 2:TiO_2 3:Al_2O_3 4:Fe_2O_3 5:FeO 6:MnO 7:MgO 8:CaO 9:Na_2O 10:K_2O 11:P_2O_5 12:H_2O+ 13:H_2O-

listed in Table 1. From the table, it is seen that the ferric iron and water contents of every mass enhance with increasing weathering, whereas the amounts of alkaline and alkaline earth elements reduce ; especially, decreases in lime and soda are clearly observed. When the individual granodiorite have been weathered from fresh to Masa, the chemical variations in them are given diagramatically in Figs. 2 to 4. Assuming that the aluminum content has remained constant throughout weathering (Harrison, 1934 ; Goldish, 1938 ; Brewer, 1955 ; and Nam and Taneda, 1974), these variations were calculated in the following way. When the contents of the individual elements in the each fresh rock are set to be 100, their relative variations, gain or loss, in each weathering stages have been computed and then these concentrations except Al_2O_3 were multiplied by the following correction factor :

$$\frac{Al_2O_3 \text{ in fresh rock}}{Al_2O_3 \text{ in any weathered rock.}}$$

As shown in figures CaO, Na_2O and FeO in every profile tend to decrease with increasing weathering, while H_2O (+), H_2O (−) and Fe_2O_3 tend to increase with weathering. No silica content in each figures shows considerable change. The rocks analyzed show little or slight enhancement in potassium content during most stages, but the potassium reduces sometimes in the final stage, Masa. There are no remarkable change in the manganese and phosphorus contents, though slight reduction in the titanium and magnesium are observed in all analyzed suites.

Reiche (1943) devised a weathering potential index (WPI) which denotes degrees of chemical weathering. This index is defined as

$$WPI = \frac{100\text{mole}\ (K_2O + Na_2O + CaO + MgO - H_2O)}{\text{mole}\ (SiO_2 + Al_2O_3 + Fe_2O_3 + CaO + MgO + Na_2O + K_2O)}$$

The values of WPI are generally reduced as weathering increases. The relationship between the WPI and the individual elements in a series of weathering rocks in Imagane are given in Figs. 5 to 9. The total H_2O, Na_2O, CaO, MgO and FeO contents in three weathering suites depend almost directly on the values of WPI, whereas K_2O for all suites are scattered on the diagram.

These chemical characteristics have been noticed not only in the granitic rocks from Imagane district but in those from Okushiri island (Shirahata, 1975). Jin-nai and Mukaiyama (1973) asserted that there was a close relation between the total H_2O and WPI for granitic rocks from Iizuka, Kyuragi and Yasu in the northern part of Kyushu, and they also pointed out the significant correlations for CaO and Na_2O.

Weathering process for granitic rocks is a history of the dissolution and alteration in their constituent minerals and, consequently, chemical changes during weathering would be related closely to mineral breakdown. From the result of microscopic observations the most unstable mineral for the weathering was plagioclase. In the incipient stage, plagioclase con-

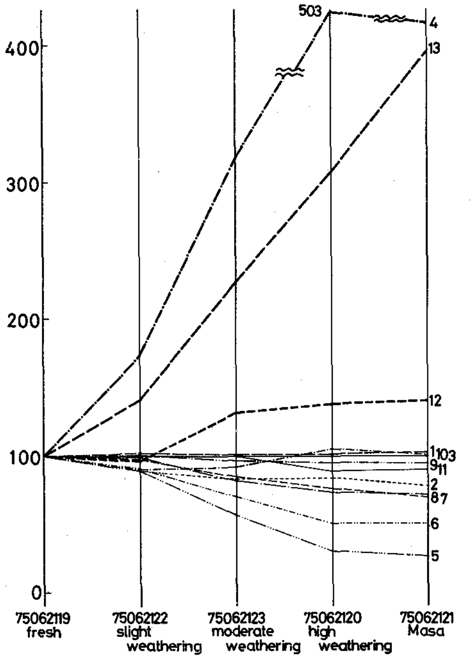


Fig. 4 Chemical variations during weathering

1: SiO_2 2: TiO_2 3: Al_2O_3 4: Fe_2O_3
5: FeO 6: MnO 7: MgO 8: CaO
9: Na_2O 10: K_2O 11: P_2O_5 12: H_2O+
13: H_2O-

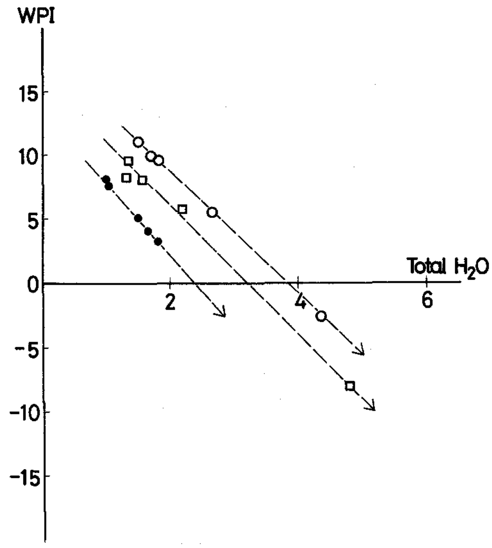


Fig. 5 Relation between WPI and Total H_2O

Solid circle ; 3.7km northern part of Pirika.
Opened circle ; 3.2km northern part of Pirika.
Square ; 5.4km northern part of Tanekawa.

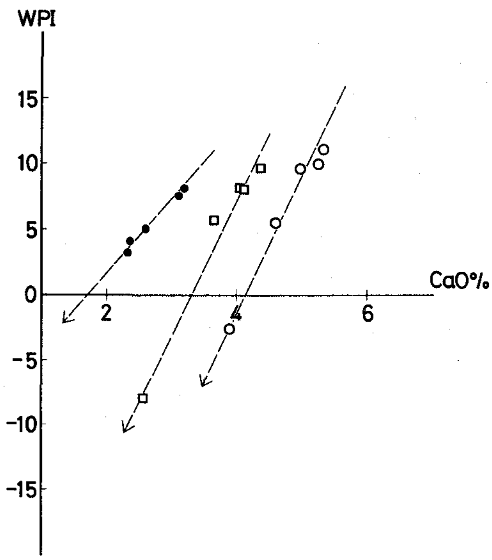


Fig. 6 Relation between WPI and CaO
The symboles are the same as Fig. 5

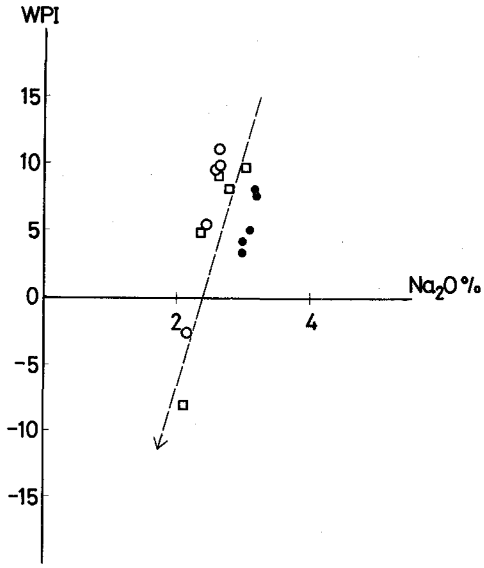


Fig. 7 Relation between WPI and Na_2O
The symboles are the same as Fig. 5

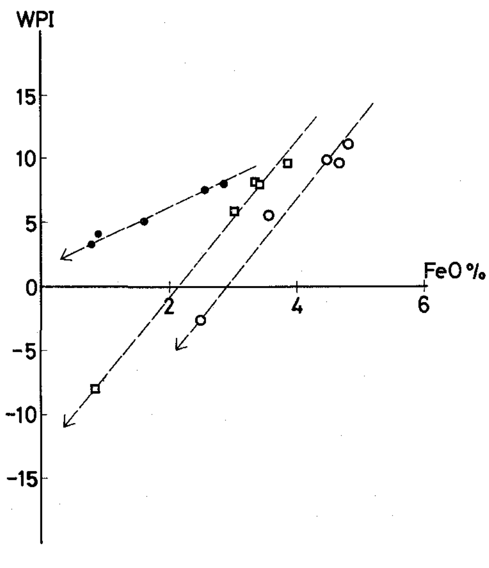


Fig. 8 Relation between WPI and FeO
The symboles are the same as Fig.5

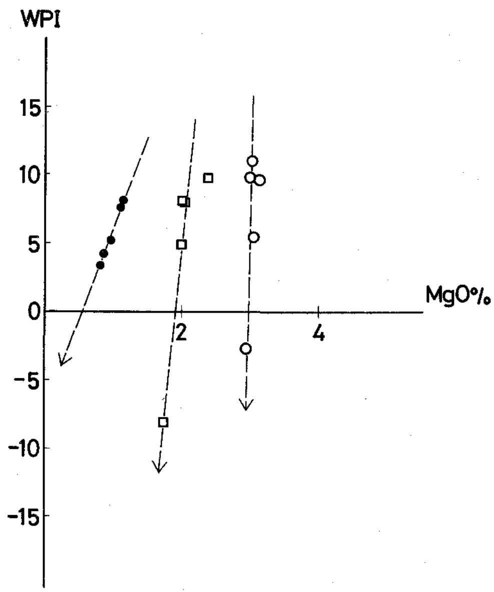


Fig. 9 Relation between WPI and MgO
The symboles are the same as Fig. 5

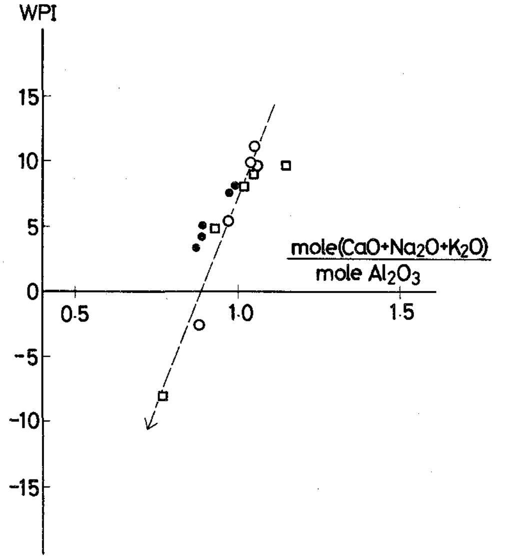


Fig.10 Relation between WPI and $\frac{\text{mole (CaO + Na}_2\text{O+K}_2\text{O)}}{\text{mole Al}_2\text{O}_3}$
The symboles are the same as Fig. 5

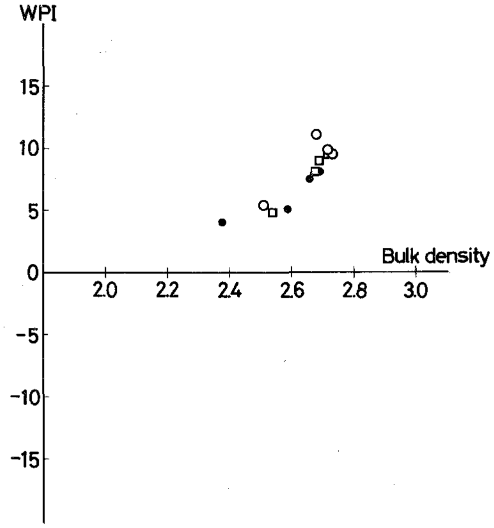


Fig.11 Relation between WPI and Bulk density The symboles are the same as Fig. 5

tained sericite. On the contrary, prominent kaoline clay is found on the plagioclase surface in the late stage of weathering. K-feldspar is gradually replaced by kaoline as weathering proceeds. Those facts must correspond directly to depletions of calsium and sodium, two main constituents of plagioclase. Ca loss process would be given by the following equation (Grant, 1963).

$$2CaAl_2Si_2O_8 + 4CO_2 + 6H_2O \longrightarrow Al_4Si_4O_{10}(OH)_8 + 2Ca(HCO_3)_2$$

A study by Kitano *et al.* (1967) supports the fact that calsium ions have been carried away in water in the form of bicarbonate. They also suggested that values Ca^{2+}(actually, Ca^{2+} + Mg^{2+}) and HCO_3^{2-} in water can be utilized as indicators of rock weathering. Sodium would be resolved the solution, as shown in the following reactions (Thompson, 1972).

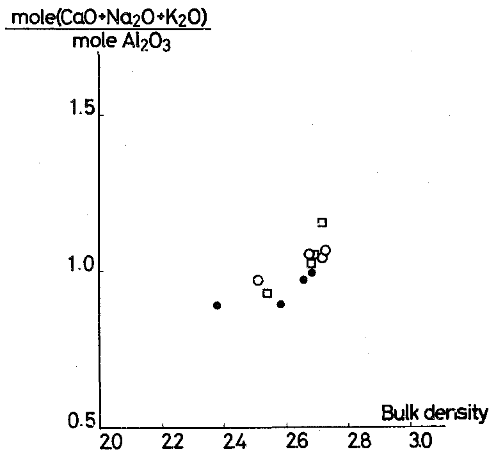


Fig.12 Relation between $\frac{\text{mole (CaO+Na}_2\text{O+K}_2\text{O)}}{\text{mole Al}_2\text{O}_3}$ and Bulk density
The symboles are the same as Fig. 5

$$\underset{\text{albite}}{2NaAlSi_3O_8} + 2H^+_{soln.} + 9H_2O_{soln.} = \underset{\text{kaolinite}}{Al_2Si_2O_5(OH)_4} + 2Na^+_{soln.} + 4Si(OH)_{4\,soln.}$$

On the other hand, it was observed that there was an irregular variation in potassium which is a mobile cation in K-feldspar. This appears to be connected with sericitization in the feld-

Table 2 Chemical weathering indices and physical properties of fresh and weathered rocks from Imagane.

	WPI	Mole ratio	Bulk density	Shore hardness
75062208	9.68	1.15	2.72	83.0
75062212	8.03	1.02	2.68	77.1
75062210	9.00	1.05	2.69	74.4
75062213	4.83	0.93	2.54	45.5
75062211	−8.15	0.77		
75062101	11.10	1.05	2.68	75.1
75062105	9.89	1.04	2.72	61.5
75062102	9.65	1.06	2.73	74.7
75062103	5.49	0.97	2.51	20.8
75062104	−2.61	0.88		
75062119	8.11	0.99	2.69	80.7
75062122	7.61	0.97	2.66	84.3
75062123	5.07	0.89	2.59	67.2
75062120	4.16	0.89	2.38	24.2
75062121	3.36	0.87		

spars. A change in magnesium content would mainly depend upon the degree of the chloritization in hornblende and biotite. Because some of ferrous iron coming out of mafic minerals is fixed, it follows that the loss of iron during weathering in each profiles is not always definite.

Miyashiro and Kushiro (1975) asserted that ratio mole ($CaO + Na_2O + K_2O$)/moleAl_2O_3 computed from chemical compositions in igneous rocks was characterized essentially by their mineral assembleges. Especially, in the fresh acid plutonic rocks the ratio should be almost 1, and then, corresponding to the transition from fresh rock to Masa, the index should be reduced to zero. Because, as mentioned above, calsium and sodium are released and washed away by water during weathering and also potassium is carried away in the final stage. Calculated mole ratios for a series of weathering rocks are tabulated in Table 2, together with their WPI, bulk densities and Shore-hardnesses, and relations between them are presented in Figs. 10 to 12. Thus this ratio is shown to be a reasonable index as a measure of weathering degree.

Summary

In order to study the weathering of granitic rocks, acid plutonic masses in Imagane were selected. Field observations support that the role of water in weathering is to regulate the weathering degree and feature. Mineralogical changes during weathering in hornblende biotite granodiorites were almost the same microscopically as in those in other humid climates (Harris and Adams, 1966 ; Jin-nai, 1973). Relative mineral stabilities, from the least stable to the most, were : plagioclase, biotite and hornblende, potash feldspar and quartz. Due to alteration of constituent minerals, chemical variations take place in each weathering suite. Assuming that alumina is constant during weathering, ferric iron and water are enriched fairly, but calsium, sodium and ferrous iron reduce gradually. Changes in silica and potassium is not definite. Depletions in manganese and phosphorous are not necessarily definite.

It was ascertained that Reiche's WPI was usefull as a measure of chemical weathering degree. Similarly the ratio mole ($CaO + Na_2O + K_2O$)/moleAl_2O_3 would be regarded as a good index of weathering degree. Moreover, both indices were directly related to bulk density of the granodiorites studied here.

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