Ishida, S., Tsuchihara, T., Imaizumi, M., Ohnishi, R., Development of radioactive prospecting as tool for evaluating degree of granitic rocks weathering.
International Symposium on the Fusion Technology of Geosystem Engineering, Rock Engineering and Geophysical Exploration
Seoul, Korea, Nov. 18-19, 2003

Development of radioactive prospecting as tool for evaluating degree of granitic rocks weathering

Satoshi Ishida, Takeo Tsuchihara, Masayuki Imaizumi, Ryouichi Ohnishi
National Institute for Rural Engineering, Tsukuba, Japan

Abstract: To develop an easy, low-cost method for evaluating the degree of weathering by radioactive prospecting, radioactive prospecting and the investigation of the degree of weathering were carried out in the southern Kitakami massif of Iwate Prefecture, Japan, in which weathering granitic rocks was distributed. Fifty outcrops in the study area were selected, and strength of the gamma-rays emitted from the weathering bedrock of ^{40}K, ^{214}Bi, and ^{208}Tl was measured for 15 minutes at each point. At the same points, soil hardness was measured on the surface of the outcrop with a Yamanaka soil penetration tester. In addition, 100cc samples of each outcrop were taken with the sampler. The samples were analyzed by XRD, and the kind of the rock-forming minerals containing K was identified. We then compared the degree of weathering and the radioactive prospecting results by using K as an indicator.

The relation between $^{40}K/^{208}Tl$ gamma rays counting rate by the radioactive prospecting and the hardness index showed a positive correlation as a result of the investigation, and the correlation coefficient (R^2) was 0.67. Moreover, when $^{40}K/^{208}Tl$ gamma rays counting rate emitted from the bedrock was low, the number of rock-forming mineral species containing K was also low. Thus, it was found that $^{40}K/^{208}Tl$ gamma rays counting rate measured by the radioactive prospecting could be used as an indicator of the degree of weathering.

1. Introduction

A large area investigation of the degree of weathering in bedrocks is required for slope disaster prevention and construction of a dam. The degree of weathering in bedrock is chiefly investigated by geological reconnaissance and mineralogical analysis. Much time and money are required for each investigations. The rock class division is used in Japan to determine of the degree of weathering by geological reconnaissance. The rock class division is empirical, requiring observer's skill. Therefore, the development of an easy, low-cost method for evaluating the degree of weathering is demanded.

The rock-forming mineral that composes the bedrock is weathered both physically and chemically, and the chemical component is leaching. Therefore, the density of the bedrock decreases, and its chemical composition changes. As a result, the radionuclide moves, and the gamma-rays emitted from the bedrock likely change according to the stage of weathering. The strength of the gamma-rays emitted from the bedrock can be measured by radioactive prospecting. The purpose of this research is to develop a method of measuring the degree of weathering in the bedrock using the radioactive prospecting.

Radioactive prospecting has been chiefly used to investigate the uranium up to now. It is also used for the examining faults, surveying caves, etc. by measuring the environmental radiation of ^{214}Bi, which is ^{222}Rn's daughter nuclide, and its use has expanded recently (Nielson et al 1990). However, there is little research on the radioactive prospecting applied to the investigation of the degree of weathering in bedrock.

The natural radionuclides that can measure gamma-rays by the radioactive prospecting are ^{214}Bi, which is the daughter nuclide of ^{238}U, ^{208}Tl, which is the daughter nuclide of ^{232}Th, and ^{40}K. Among these three nuclides, Th is least moved by weathering (Katayama 1961), while K is moved mostly (Miura 1975) by weathering. The investigation of the degree of weathering and radioactive prospecting were carried out in this research on granitic rocks that contained comparatively large amount of K, and the results were compared.

2. Principle of radioactive prospecting

Radioactive decay is a statistical process in which the number of atoms that disintegrate per unit time is proportional to the number of atoms present. A few nuclides are radioactive and decay to produce other nuclides.

The uranium isotopes of ^{238}U,^{235}U, and ^{232}Th decay into intermediate daughter products and ultimately into stable ^{206}Pb, ^{207}Pb and ^{208}Pb. In the process, alpha particles are emitted. The gamma-rays of many discrete energy levels are emitted from ^{226}Ra, ^{214}Bi, and ^{214}Pb in a ^{238}U radioactive decay series, and from ^{208}Tl in a ^{232}Th decay series. The potassium isotope ^{40}K emits gamma-rays of 1.46 MeV through electron capture.

When the half-life of the parent nuclide is much longer than the half-life of the daughter nuclide in a decay series, the ratio of daughter activity to parent activity is constant at 7-10 times the half-life of the daughter. This state is called "radioactive equilibrium". The amount of the parent nuclide can be measured by measuring the number of gamma-rays emitted from the daughter, in the state of radioactive equilibrium. Based on this principle, the amounts of ^{238}U in uranium surveying and ^{222}Rn in fault surveying are measured from the gamma-rays of ^{214}Bi. Similarly, the amount of ^{232}Th is measured from the gamma-rays of ^{208}Tl.

The pulse wave height distribution obtained by the gamma-ray spectrometer is called a gamma-ray spectrum. Gamma-ray emitted nuclides are identified on the basis of gamma-ray spectrum. The detector of the gamma-ray spectra includes the NaI(Tl) scintillation detector (hereafter called NaI) and the semiconductor detector (Ge(Li) detector and Si(Li) detector). The semiconductor detector has good energy resolution (about 2 KeV), and can express the relationship between energy and the pulse height by a linear equation. However, it is not generally used in field surveys because its counting yield is defectively low and it is troublesome to operate. Although the energy resolution (5-8 %) of the NaI is inferior when compared with the other detectors, NaI is usually used for gamma-ray spectrometry because its counting yield is high and operation is easy.

In standard practice, three quantities are measured in gamma-ray spectrometry using NaI (resolution 7 %): ^{40}K = radioactive potassium content via an integrated count between 1.37 and 1.57 MeV (the peak of ^{40}K is 1.46 MeV); ^{238}U or ^{222}Rn = uranium or radon via an integrated count between 1.66 and 1.86 MeV (the peak of ^{214}Bi is 1.76 MeV); ^{232}Th = thorium via integrated count between 2.42 and 2.81 MeV (the peak of ^{208}Tl is 2.62 MeV)(Fig.1).

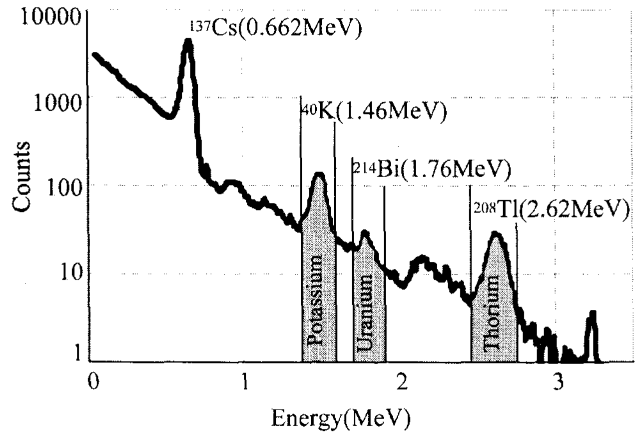

Fig. 1. Gamma-ray spectra of potassium, thorium and uranium. (Shaded bands indicate the positions of spectral windows used for survey.)

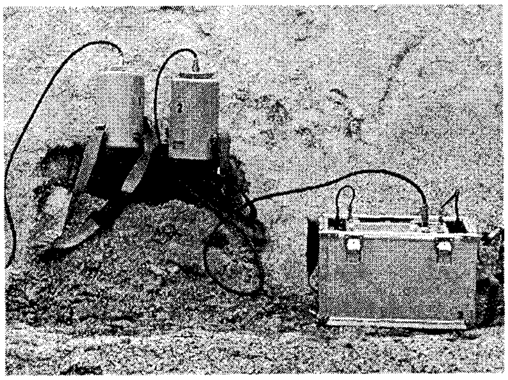

Photo. 1. Man-borne type gamma-ray radioactive prospecting devices.

When a person carries a gamma-ray radioactive prospecting device, this method is called "man-borne" (Photo.1). It is called "car-borne" when the investigation is conducted while driving and stopping in a car containing the device. It is called "heli-borne or air-borne" when the investigation is performed from a helicopter or airplane. Gamma-rays within the range of 1.46～2.62 MeV attenuate when they pass through the rocks and the surface of the earth. About 90% of all gamma-rays from rock of density 2.7 g/cm^3 have their origin within a range of 15～22.5 cm in depth from the surface.

3. Description of the topography and geology of the study area

The study area is located in the Senmaya district in the southern part of the Kitakami Mountains, Northeast Japan (Fig.2). The Kitakami Mountains belong to the geological district of the Southern Kitakami Range where Palaeozoic stratified rocks and Cretaceous intrusive granites are mainly distributed. The topography of the Southern Kitakami Range shows a dissected peneplain with several planation surfaces. The Senmaya district is underlain by Carboniferous to Triassic sedimentary rocks and Lower Cretaceous volcanic rocks which are intruded by Early Cretaceous granitic rocks and porphyritic dikes. The study area covers about 1.5km^2 where the Cretaceous granitic rocks (Senmaya pulton) are distributed (Takeuchi & Mikoshiba 2001 : Fig.3). Palaeozoic and Mesozoic Sedimentary rocks with intrusive granitic rocks surround the study area. The topographic features of the Senmaya district are a dissected hilly area with gentle slope, and the plain deposit forms a long and slender planation surface along the valley. A almost of the granitic rocks in the study area are deeply weathered into sandy structures with residual boulders of granite (Photo.2) except for several new road cuts. The residual boulders of granite show an onion-like structure of concentric shells of rusty and rotted residual material with a core of fresh granitic rock. The size of residual boulders ranges from tens of cm to 2 m. The residual ratio of boulder to sandy part in outcrops ranges from 0 % to 30 %.

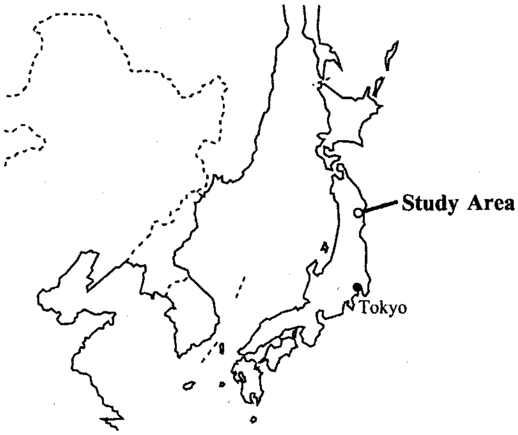

Fig. 2. Study area.

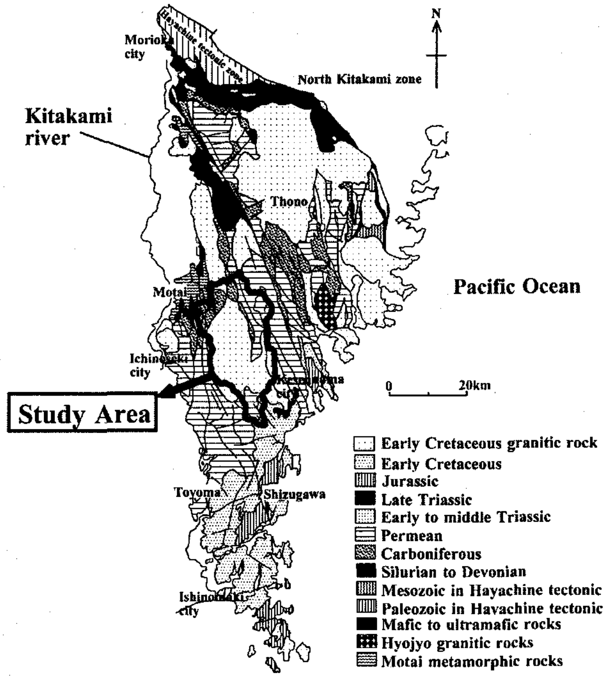

Fig. 3. Geological map of study area.

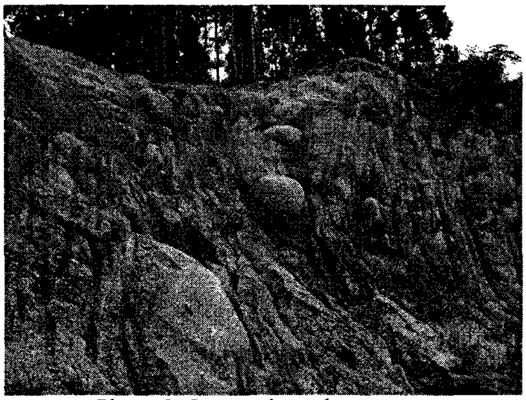
Photo. 2. Outcrop in study area.

4. Method

In general, the degree of weathering is expressed by the 6 levels (A, B, CH, CM, CL, D (subdivided DH, DL)) of rock classification. The rock of A level is a fresh rock without any cracks. The rock of D level is a strongly weathered rock with softness like soil. The rock classification is decided on the basis of observation with the naked eye, shock sound of hammer and crack frequency. A good correlation between data of many rock classifications and mechanical test results shows the validity of the rock classification.

Fifty outcrops in the study area were selected to study on the relationship between the rock classification, and radioactive prospecting and the investigation of the degree of weathering.

Radioactive prospecting

Portable pulse height analysers made by Clearpulse Co., Ltd. and scintillation detector (NaI crystal-like cylinder of 13 cm in diameter and height with a photo multiplier tube) were used for man-borne measurements. A detector with energy resolution of 7 % or less was used. The NaI detector was put on the ground surface to measure. ^{40}K = 1.37-1.57 MeV, ^{214}Bi = 1.66-1.86 MeV, and ^{208}Tl = 2.42-2.81 MeV. Each measurement time was fifteen minutes. ^{40}K, which is 0.0117 % of isotopic abundance of K, was expected to be an indicator of the degree of weathering. However, because ^{208}Tl is the daughter nuclide of ^{232}Th, which is less moved by weathering than K, ^{40}K/^{208}Tl rate would be a better indicator of degree of weathering.

Investigation of the degree of weathering

The degree of weathering is studied with two indicators: hardness of weathered granitic rocks and the amount of mineral containing K^+ such as K-feldspar and biotite. Mori et al. (2001) show a good relationship between the hardness index measured by the Yamanaka soil penetration tester and the rock classification of the bedrock at an outcrop at the construction site of Takashiba reservoir in Fukusima Pref., Japan. The Yamanaka soil penetration tester (Photo.3) was used for measuring the hardness of wreathed granitic rocks with sandy structure.

The soil penetration tester consists of a conic body with a built-in spring and needle. The hardness index is measured as penetration length (unit in mm) against the spring of resistance strength 8 kg shrinks when the investigator vertically pushes the needles into the outcrop up to a predetermined depth. Ten measurements were taken with of the soil penetration tester at each outcrop, and the mean was adopted. The amount of mineral containing K^+ was measured by the X-ray diffraction method XRD (Philips X'PertMPD).

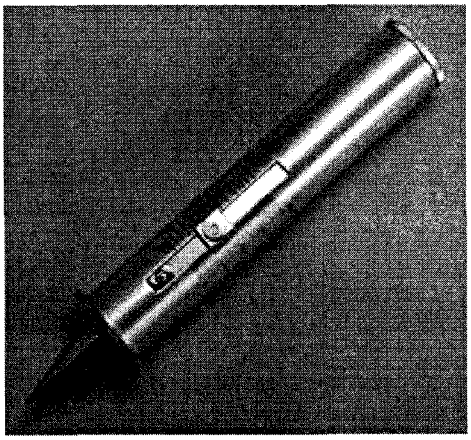

Photo. 3. Soil penetration tester.

5. Results and discussion

The radioactive prospectings at many points within one outcrop of sandy weathered rock with residual boulders show that the ^{40}K/^{208}Tl rate ranged from 5.0 to 11.5. Most of the points with a 40K/208Tl rate of 10 or more are classified as C_L or higher class of rock.

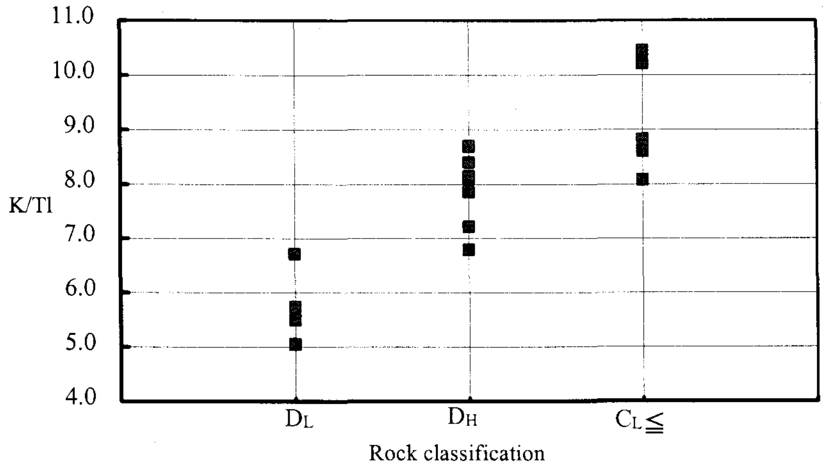

Fig. 4. Relation between K/Tl ratio and rock classification.

The hardness index is in the range of 18-34mm, but few outcrops with a 30mm hardness index are distributed in the study area. Fig.4 shows the relation between the $^{40}K/^{208}Tl$ rate and rock classification. Fig.4 shows that $^{40}K/^{208}Tl$ rate tends to increase with rock classification.

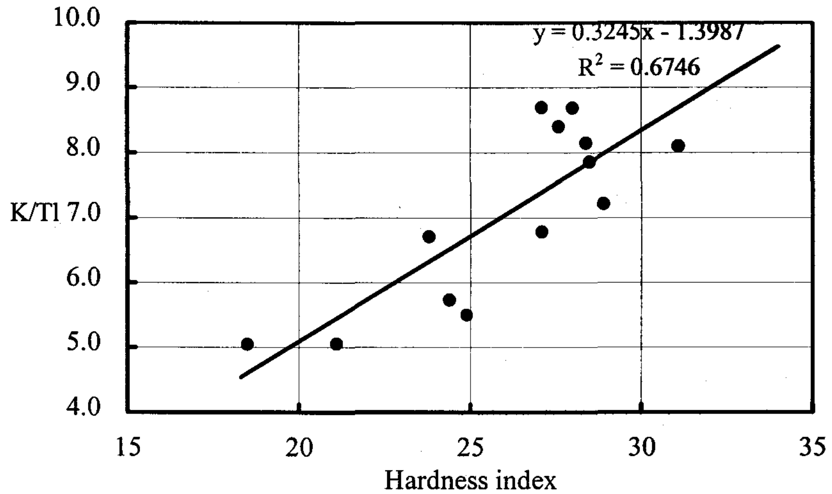

Fig. 5. Relationship between the $^{40}K/^{208}Tl$ rate and the hardness index.

Fig.5 shows that $^{40}K/^{208}Tl$ tends to increase with the hardness index. The relation shows a positive correlation coefficient (R^2) between the $^{40}K/^{208}Tl$ rate and the hardness index of 0.67. These results seem to suggest that K is leaching as weathering progresses, and the relative K content ratio has decreased.

A powdery X-ray diffraction method identifies six kinds of rock-forming minerals containing K^+ (biotite, muscovite, orthoclase, anorthoclase, sanidine and microcline) in sandy weathered rock. There was no sample that contained all six of these minerals. Outcrops containing biotite, which is one of the original rock-forming minerals were rarely found in the study area. Muscovite and microcline, which are formed under lower temperature than the other minerals, may be secondary minerals. They are very common minerals in the study area. Occurrences of only muscovite or microcline, or a combination of two minerals, may be an indicator of the degree of weathering. The $^{40}K/^{208}Tl$ rate at outcrops with the minerals or mineral combinations tends to have a high numerical value. This tendency seems to show that the mineral in the bedrock is leaching as weathering advances, and as a result, the content of K and the radioactivity decrease.

6. Conclusions

In this research, the degree of weathering was investigated and radioactive prospecting was conducted of fifty outcrops in a weathered granitic rock region, with the following results. The relation between $^{40}K/^{208}Tl$ gamma rays counted by the radioactive prospecting and the value derived from the hardness index showed a positive correlation When the gamma rays count of $^{40}K/^{208}Tl$ emitted from the bedrock was low, the number of mineral species containing K was also low. Thus, the gamma rays count of $^{40}K/^{208}Tl$ measured by radioactive prospecting can be used as an indicator that shows the degree of weathering.

One caveat about this method is, when it is used to indirectly measure changes in the chemical composition by weathering of the material, this method cannot be used in the field where the chemical compositions of original rocks are not the same. It is thus necessary to take the geological information into consideration when selecting investigation points for this method.

References

Nielson, D. L., Linpei, C. and Ward, S. H., 1990, Gamma-ray spectrometry and radon emanometry in environmental geophysics, Geotechnical and Environmental Geophysics, Vol.1, Society of Exploration Geophysics, 219-250

Katayama, N., 1961, General Remarks, Uranium - Its resource and mineral -, Asakura Book Corporation, 1-12 (In Japanese)
Miura, K., 1975, The Weathering of Daito Granodiorite Mass, Shimane Prefecture, Japan, J. Japan Soc. Eng. Geol., Vol.16, No.2, 48-55 (In Japanese with English abstract)
Takeuchi, M., & Mikoshiba, M., 2001, Geology of the Senmaya District, Geological Survey of Japan, 74-75 (In Japanese with English abstract)
Mori, M., Bizen, N., Mouto, H., 2001, Rock classification of D-class Granite basin using the index of Impact Acceleration, Proceedings of The Japanese Society of Irrigation, Drainage and Reclamation Engineering annual meeting in 2001, 432-433 (In Japanese)