[論文] 沖縄島に分布する石灰岩の諸性質

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Some Physical and Mechanical Properties of the Limestones in Okinawa Island

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Introduction

Limestones are highly soluble in acid waters and form distinctive landscapes called "karst landforms." The karst landform features in Japan have been controlled by the solution rate of limestones which is affected by the partial pressure of soil (Mezaki, 1984), groundwater and atmospheric CO_2, and rock structure such as joints and porosity. Maekado (1988) clarified that the solution rate in Okinawa Island is related to the porosity of the limestones. Few studies on the properties of the limestones in Ryukyu Islands have been done (e.g., Kaneshima, 1965; Shinjo and Nakamura, 1975). They examined specific surface area and porosity of the limestones except for the Triassic in Ryukyu Islands. As the first step to clarify the solution rate of the limestones in Okinawa Island, the present study investigates some physical and mechanical properties of the limestones including Triassic.

Limestones of Okinawa Island

Okinawa Island is underlain by Permian, Triassic and Quaternary limestones (Fig.1, Table 1). The Permian limestone (about 250 My B.P.), named "Motobu Limestone" by Flint *et al.* (1959), is found in Motobu Peninsula and in Kunigami and Ōgimi Villages in the northern part of Okinawa.

Motobu Peninsula and Kunigami Village is also underlain by the Triassic limestone named the Nakijin Formation (Ishibashi,1969), whose age is about 200 My B.P.

Yabe and Hanzawa (1930) have mentioned the Quaternary Riukiu (Ryukyu) Limestone. Flint *et al.* (1959) subdivided Ryukyu Limestone into three formations, i.e., Naha Formation (the Naha Limestone), the "Yontan" (Yomitan) and the "Machinato" (Makiminato) Limestone ascendingly. The Naha Limestone (hundreds of thousands of years B.P.) occurs mainly in the central and southern parts of Okinawa (Kizaki *et al.*, 1984 ; Kawana, 1988,p.76). The Yomitan Limestone (200,000—230,000 years B.P.) is exposed in Yomitan Village, the central part of Okinawa (Konishi, 1980 ; Koba *et al.*, 1985 ; Kawana, 1988, p.78). The Makiminato Limestone (120,000—130,000 years B.P.) is developed mainly in Gushikami and Tamagusuku Villages in the southern part of Okinawa (Konishi, 1980 ; Omura, 1983 ; Kawana, 1988, p.80).

Samples and Methods

Samples tested were taken from ten localities (Fig. 1). A fresh limestone mass was sampled by digging outcrop surfaces. The Motobu Limestone

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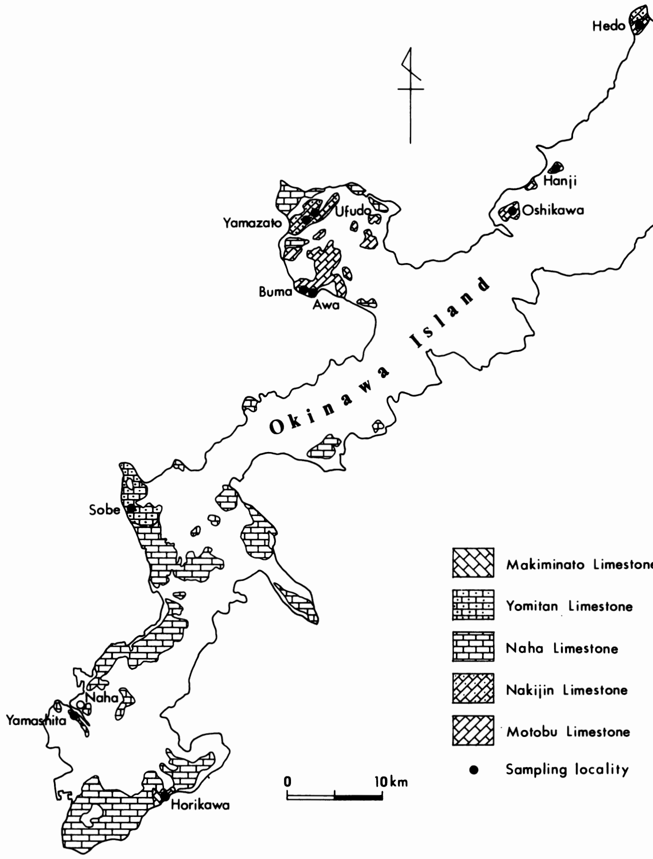

Fig.1. Limestones in Okinawa Island and sampling locality (modified after Kizaki and Hayashi, 1985).

was collected from Hedo and Hanji in Kunigami Village, Oshikawa in Ōgimi Village, and Buma and Awa in Nago City. The Nakijin Limestone was taken from Ufudo and Yamazato in Motobu Town. The Naha Limestone was gathered from Yamashita in Naha City, the Yomitan Limestone from Sobe in Yomitan Village, and the Makiminato Limestone from Horikawa in Tamagusuku Village.

Physical properties of the limestones were examined on specific gravity, dry unit weight, and porosity for the specimens sampled from ten localities shown in Fig.1. Rebound hardness of the Schmidt Hammer Test was measured as one of the mechanical properties in the field.

Specific gravity (G_S) test was carried out by using powder specimens according to the Japanese Industrial Standards (JIS) A 1202. Dry unit weight (γ_d) was obtained by dividing the weight by the volume of specimens. The shape of the specimens is a cube, whose length, width, and height are about 3 cm. Volume of the specimens was tested by using a cylinder. Porosity (n) was calculated from the data of specific gravity and dry unit weight. The equation is expressed by

$$e = \frac{G_S \quad \gamma_w}{\gamma_d} - 1 \qquad (1)$$

Table 1. Stratigraphic sequence of the limestones in Okinawa Island (Furukawa, 1985 ; Kizaki and Hayashi, 1985) .

Cenozoic	Quaternary	Holocene	
		Pleistocene	Makiminato Limestone
			Yomitan Limestone
			Naha Limestone
	Tertiary		
Mesozoic	Cretaceous		
	Jurassic		
	Triassic		Nakijin Limestone
Paleozoic	Permian		Motobu Limestone

$$n = \frac{e}{1+e} \times 100 \qquad (2)$$

where e is the void ratio, G_S the specific gravity, γ_w the unit weight of the water, γ_d the dry unit weight of the rock, n the porosity.

The rebound hardness of the Schmidt Hammer Test (R) was obtained by means of 10 measurements of Schmidt Test Hammer.

Results

Test results are listed in Table 2. The Motobu, Nakijin, Naha, Yomitan and Makiminato Limestones have a specific gravity of 2.70 –2.72. The specific gravity of the Permian, Triassic and Quaternary limestones is nearly equal.

The dry unit weight (γ_d) of the Motobu and Nakij in Limestones is 2.62–2.72 (gf/cm^3) and that of the Naha, Yomitan and Makiminato Limestones ranges from 1.40 to 2.29 (gf/cm^3). The dry unit weight of the Permian and Triassic limestones is larger than that of the Quaternary limestone. The specific gravity is similar in the Permian, Triassic, and Quaternary limestones. Therefore, it is considered that smaller dry unit weight in the Quaternary limestone is related to the many pores in the limestone.

Porosity (n) of most Motobu and Nakijin Limestones is 0%, while porosity of the Quaternary limestone increases with a decrease in the age of the limestones. The Makiminato Limestone especially shows a high value (48.4%). The values in the Motobu, Naha, and Yomitan Limestones are nearly equal to the values obtained by Shinjo and Nakamura (1975). However, they obtained smaller values in the Makiminato Limestone.

The rebound hardness of the Schmidt Hammer Test (R) of the Motobu and Nakijin Limestones is 46.0 –57.9%, while that of the Naha, Yomitan and Makiminato Limestones is 21.5 –38.4%. The rebound hardness of the Schmidt Hammer Test of the Permian and Triassic limestones is larger than that of the Quaternary limestone.

Fig. 2 illustrates the relationship between the porosity (n) and rebound hardness of the Schmidt

Table 2. Some physical and mechanical properties of the limestones.

Rocks	Sampling Locality	G_s	γ_d (gf/cm³)	n (%)	R (%)
Motobu Limestone	Hedo, Kunigami	2.72	2.71	0.4	46.0
Motobu Limestone	Hanji, Kunigami	2.71	2.62	3.3	48.8
Motobu Limestone	Oshikawa, Ōgimi	2.72	2.72	0	49.7
Motobu Limestone	Buma, Nago	2.71	2.71	0	50.4
Motobu Limestone	Awa, Nago	2.70	2.70	0	51.1
Nakijin Limestone	Ufudo, Motobu	2.72	2.72	0	50.2
Nakijin Limestone	Yamazato, Motobu	2.72	2.72	0	57.9
Naha Limestone	Yamashita, Naha	2.70	2.29	15.2	38.4
Yomitan Limestone	Sobe, Yomitan	2.70	2.24	17.0	29.7
Makiminato Limestone	Horikawa, Tamagusuku	2.71	1.40	48.4	21.5

G_s : Specific gravity, γ_d : dry unit weight, n : porosity, R : rebound hardness of the Schmidt Hammer Test.

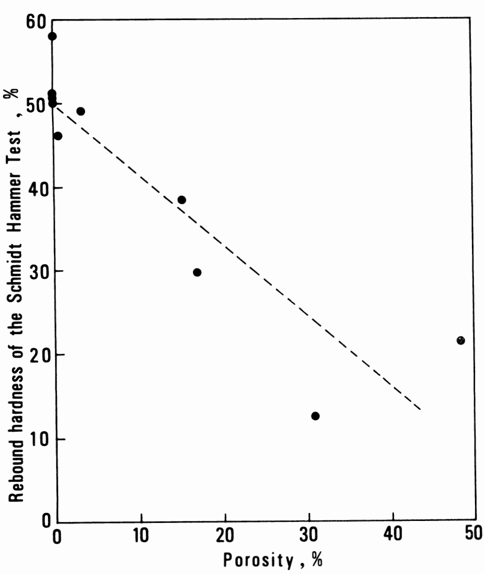

Fig.2. Relation between porosity (n) and rebound hardness of the Schmidt Hammer Test (R).

Hammer Test (R) . The rebound hardness of the Schmidt Hammer Test (R) tends to decrease when porosity (n) increases. Thus, the rebound hardness of the Schmidt Hammer Test has a correlation to porosity.

Summary

The Permian and Triassic limestones have smaller porosity and larger rebound hardness of the Schmidt Hammer Test than the Quaternary limestone. The rebound hardness of the Schmidt Hammer Test decreases with an increase in porosity.

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沖縄島に分布する石灰岩の諸性質

前門　晃*

石灰岩の溶食速度を決める重要な性質である空隙率を中心に，これまで調べられなかった三畳系石灰岩を含め，沖縄島に分布する石灰岩の諸性質を測定した．その結果，(1)比重は二畳紀・三畳紀の古期石灰岩，第四紀の新期石灰岩とも 2.70～2.72 の値をもち大差ない，(2)乾燥単位体積重量は古期石灰岩が 2.62～2.72（gf/cm³）を示し，新期石灰岩の 1.40～2.29（gf/cm³）に比べて大きい，(3)空隙率は古期石灰岩の大部分が 0 %，新期石灰岩では年代の新しいもの程大きくなっている，(4)シュミットロックハンマー反発値は古期石灰岩で 46.0～57.9%を示し，新期石灰岩の 21.5～38.4%より大きく固結度が高い，(5)空隙率とシュミットロックハンマー反発値との間には，空隙率が大きくなるにつれてシュミットロックハンマー反発値が小さくなる傾向がみられる，ことが明らかとなった．

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