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Karst Geomorphology

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THE SOLUTION RATE OF LIMESTONE TABLETS AND CO₂ MEASUREMENTS IN LIMESTONE AREAS OF JAPAN

ABSTRACT: URUSHIBARA-YOSHINO K., MIOTKE F. D. & RESEARCH GROUP OF SOLUTION RATES IN JAPAN, *The Solution Rate of Limestone Tablets and CO₂ Measurements in Limestone Areas of Japan*. (IT ISSN 0391-9838, 1998).

In order to clarify the main factors for karstification in the world, comparative measurements of the solution rate of lithologically identical limestone tablets are being carried out in several countries of the world. In this study, seven measurement points ranging from north (Hokkaido), to south (Minamidaito Island), were chosen in Japan. At each point, the solution rates of limestone tablets in air and in soil were observed. In addition, the water balances were calculated and the CO₂ contents of the soils were measured.

In 1993, the annual mean air temperature was low and annual precipitation was above normal. The solution rates of limestone tablets in 1993 were high at all measurement points. In 1994, when a dry period prevailed, the CO₂ contents of the soils were low, and solution rates of limestone were low, especially in the southern parts of Japan.

The solution rates of limestone tablets in the soil B2 horizon show a high correlation coefficient with annual precipitation and soil CO₂ level.

KEY WORDS: Limestone degradation, Climate, Soil, Japan

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INTRODUCTION AND METHODS

In reference to karstification in the world, many karstologists have studied the factors affecting the solution of limestone. Significant factors are climate, CO₂, lithological variety of limestone and ecological conditions. However, the solution rates of limestone all over the world have yet to be measured for all karsts. A commission of the International Speleological Union measured the solution rates of Slovenian Cretaceous limestone tablets in several countries commencing in 1980. The results were published by Gams (1985). In the same context, limestone tablets made of Quillin Permian limestone were examined to measure solution rates in China (Yuan, 1991). The solution rates of Slovenian limestone in Japan were also measured from 1989 to 1990 by Urushibara (1991).

This paper reports on the measurement of limestone solution rates in Japan over a period of 3 years, 1993, 1994 and 1995. The role of CO₂ in the corrosion of limestone tablets in soils was also examined over these three years.

Seven karst areas were chosen from north to south in Japan, Asahikawa, Abukuma, Chichibu, Akiyoshidai, Shikoku, Ryugado and Minamidaito Island (fig. 1). In each location, 4 limestone tablets were set at each of three levels: in the air 1.5 m above the ground, and in the soils of A3 horizon and B2 horizon, making a total of 12 tablets per site. The four tablets measured at each level were made of Slovenian Cretaceous limestone, Quillin Permian limestone, Chichibu Triassic limestone and a sample of limestone from the local area.

The tablets had a diameter of 40 mm, with a thickness of 4 mm. Before placing in the soil, the surface of the tablet was ground by 300 mesh, and weighed when dry. Ea-

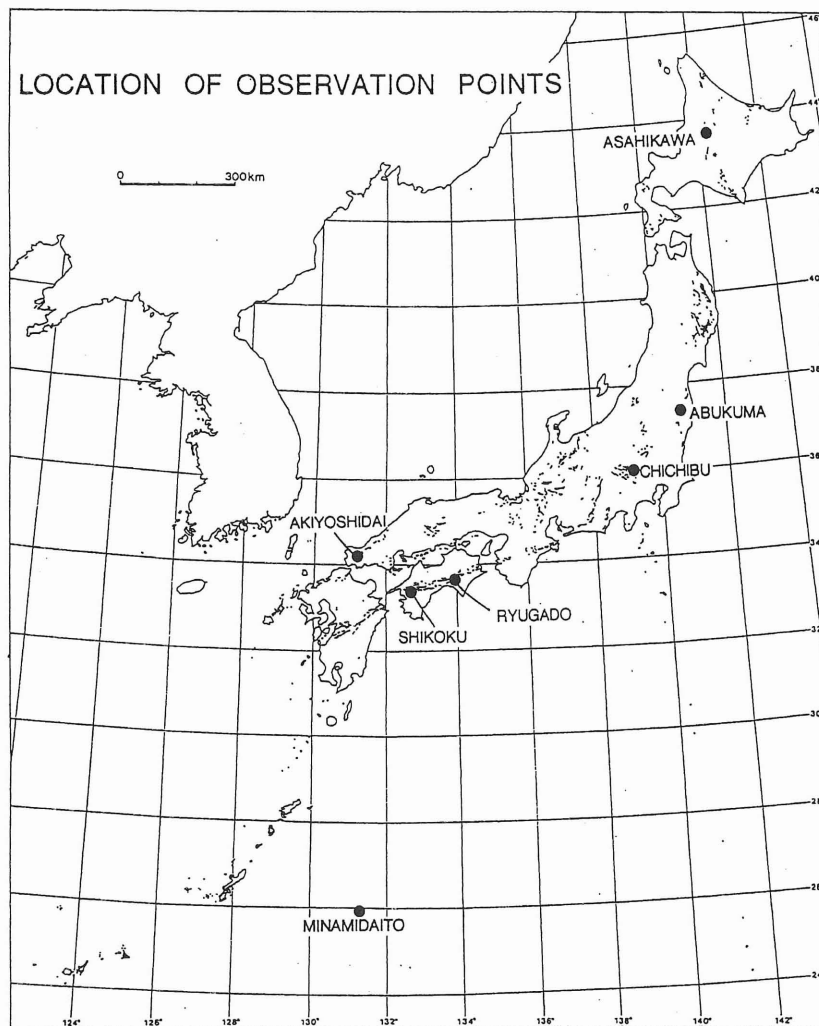


FIG. 1 - Limestone areas and locations of observation points in Japan.

ch year, the weight of tablets was measured and compared. Then the weight loss was calculated as the solution rate for that year.

The CO₂ contents in the soils were measured in the A3 and B2 horizons where tablets were placed. The results at Abukuma and Minamidaito Island were compared using three methods: a Non-dispersive Infrared Gas Analyzer, a Gastec method and a Dräger method (Miotke, 1974). The data gathered by the Gastec method showed a 5-10% error compared with the standard data of the Non-dispersive Infrared Gas Analyzer. In heavy clay areas, for example Minamidaito Island, data could not be obtained by the Dräger method. Therefore the Gastec method was used in all seven locations for all measurements.

The water balance in 1993, 1994 and 1995 was calculated using the Thornthwaite Method of 1948. The annual water surplus and water deficits were examined in relation to solution rates. The climate in 1993 was extremely wet and cool, but, in contrast, 1994 was very warm and dry. In 1995, it was dry in southern Japan and wet in northern Japan.

SOLUTION RATES

The solution rates of four tablets at each site and level were compared. High rates of solution of Quillin limestone were observed in almost every case in the air and in the soils. The Quillin limestone tablets show 10 - 16% higher solution rates than the other limestones, especially in the case of wet soils. However, for the sake of simplicity, the average solution rates of the 4 tablets at each site and level were used. The solution rates of limestone tablets in the air 1.5 m above the ground clearly increased in 1993 in accordance with annual precipitation. During 1994, the solution rate in the air became very low, especially in the southern part of Japan. By the Thornthwaite method, the solution rate at 1.5 m above the ground during the three years shows the highest positive correlation with WS-WD (water surplus-water deficit).

In the soils, the solution rates were always 1.5 times higher in B2 horizons than in the air 1.5 m above ground level. In 1993, a cool and wet year, the solution rates in B2 horizons were high in comparison to 1994, a warm, dry

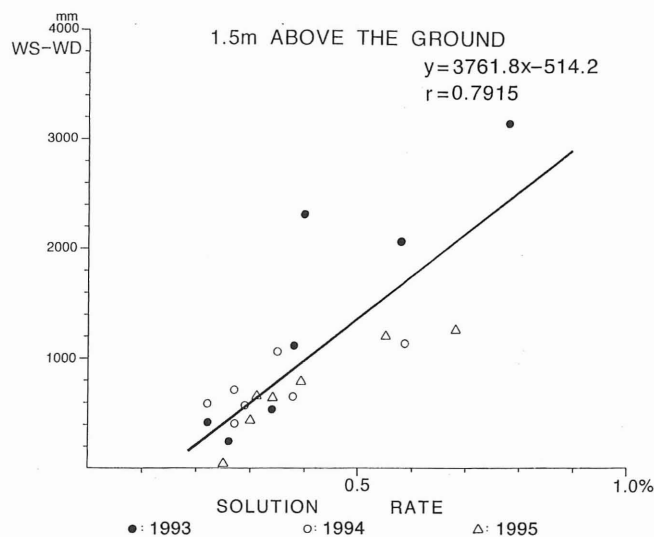


FIG. 2 - Correlation between solution rates of limestone in 1.5 m above the ground and annual precipitation.

year. The solution rates for the three years increased with annual precipitation. The highest correlation coefficient is between solution rates in B2 horizon and annual precipitation (fig. 3). The second highest correlation coefficient is between solution rates in the B2 horizon and water surplus using the Thornthwaite method (1948). Correlation coefficients are shown in Table 1

TABLE 1 - Correlation Matrix of 3 years (1993-1995) between solution rates of limestone and climatic factors

	PREC.	WS	WS - WD	P - E
1.5 m ABOVE THE GROUND	r = 0.726	r = 0.785	r = 0.792	r = 0.785
A ₃ HORIZON	r = 0.509	r = 0.452	r = 0.437	r = 0.428
B ₂ HORIZON	r = 0.566	r = 0.475	r = 0.456	r = 0.446

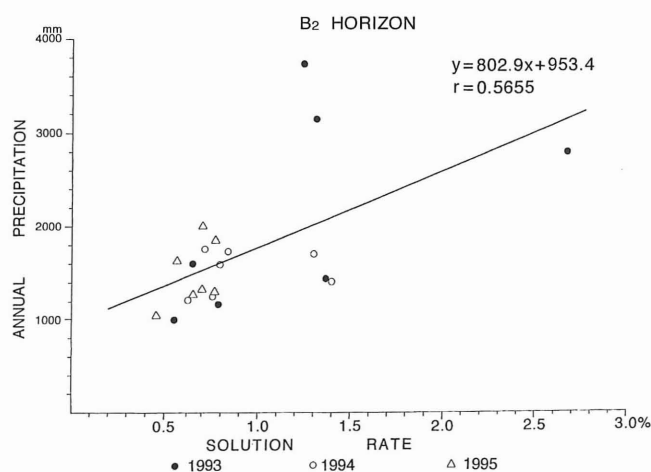


Fig. 3 - Correlation between solution rates of limestone in B2 horizon and annual precipitation.

CO₂ MEASUREMENTS

The three methods used, Gastec, Non-dispersive Infrared Gas Analyzer and Dräger were compared at Abukuma and Minamidaito Island. CO₂ by the Dräger method was variable even within an area of 5m². In the heavy clay area at Minamidaito island, it was not possible to measure soil CO₂ in the B2 horizon by the Dräger method. The values obtained using the Gastec method include an error of 10% when compared with the Non-dispersive Infrared Gas Analyzer. The CO₂ values were measured by the Gastec method in the A₃ and B₂ horizons of the soils at the seven locations. The observed CO₂ values and climatic condition in 1993 and in 1995 at Minamidaito island are shown in fig. 4. Soil CO₂ increased dramatically 3-4 days after heavy rain. In most seasons, the soil CO₂ in B₂ horizons was higher than in A₃ horizons. In 1995, soil CO₂ showed a sharp contrast between the wet and the dry conditions.

The August soil CO₂ in the B₂ horizon for the seven sites in 1993, 1994 and 1995 are shown with monthly mean air temperature and the preceding month's total precipitation (fig. 5). When both the monthly mean air temperature and the one month total precipitation before measurements are high, the soil CO₂ values are also high. The annual fluctuation of soil CO₂ in B₂ horizons in August is clear. When both factors, monthly mean air temperature and one month total precipitation are high, the soil CO₂ values are extremely high, especially at over 28°C monthly mean air temperature and over 200 mm one month total precipitation in Minamidaito, 1993. However, below 20°C monthly mean air temperature, even if the one month total precipitation is over 1,000 mm, soil CO₂ was less than 1% in Shikoku, 1993.

The February soil CO₂ in the B₂ horizon in 1993, 1994 and 1995 are shown with monthly mean air temperature and one month total precipitation before measurements of soil CO₂ in fig. 6. The ranges of soil CO₂ are small at all seven points, and the relationship between CO₂, monthly mean air temperature and the prior month's precipitation is not clear. Only at Minamidaito Island are the measurements of soil CO₂ always high.

CONCLUSIONS

- (1) Solution rates of limestone tablets in the air 1.5 m above the ground show highest correlation coefficient with WS-WD by the Thornthwaite method.
- (2) Solution rates of limestone tablets in B₂ horizon show highest correlation coefficient with annual precipitation.
- (3) High solution rates of limestone in the air and in soils are a reflection of the wet conditions in Japan.

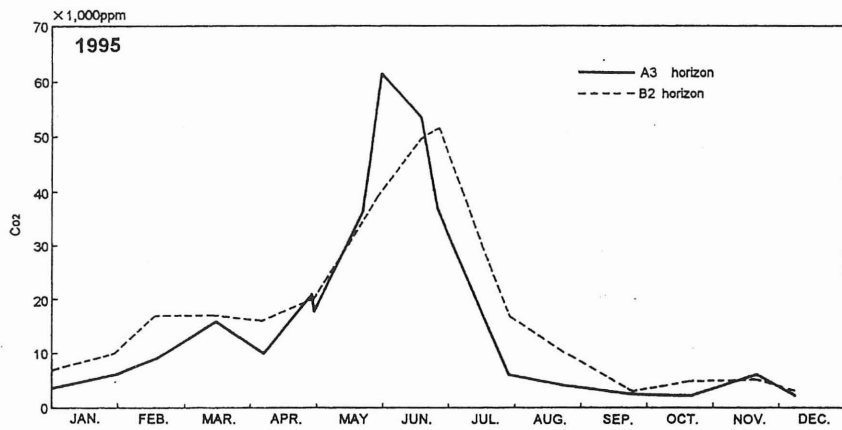
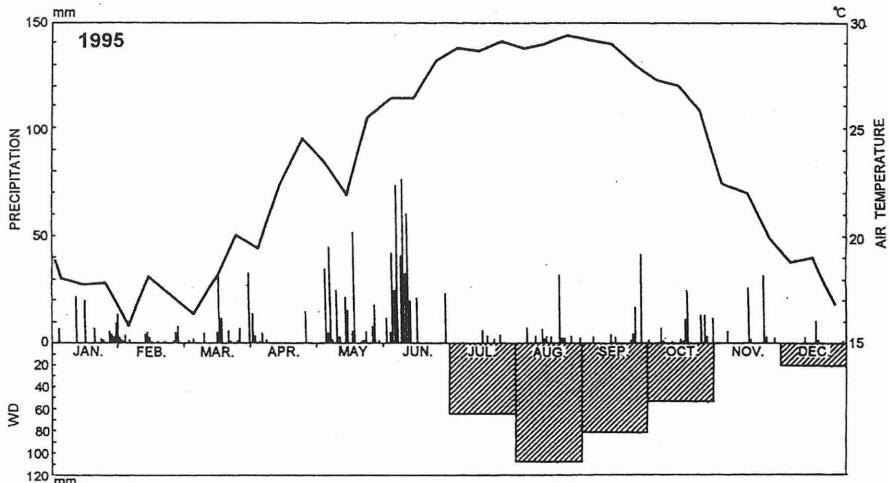
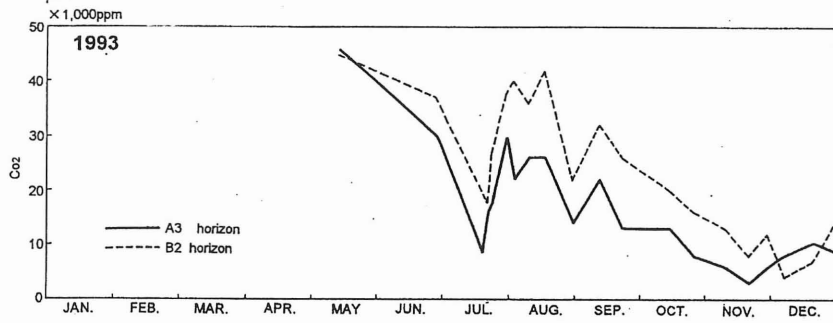
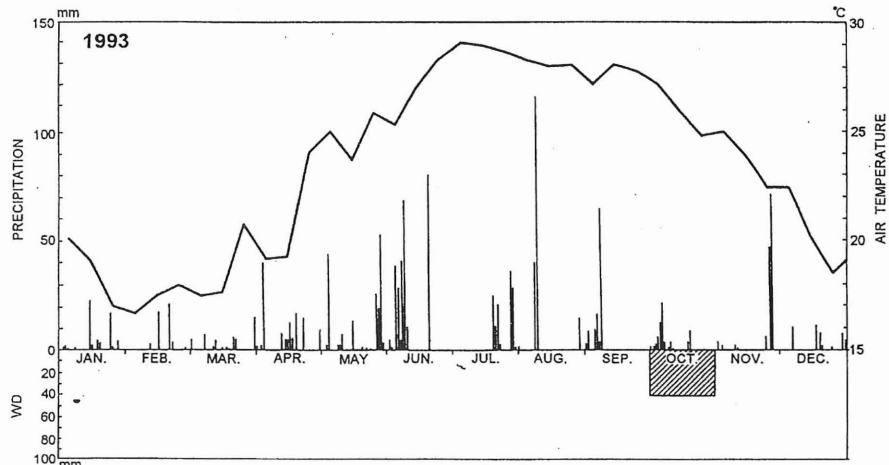


Fig. 4 - CO₂ values and climatic conditions at Minamidaito Island in 1993 and 1995.

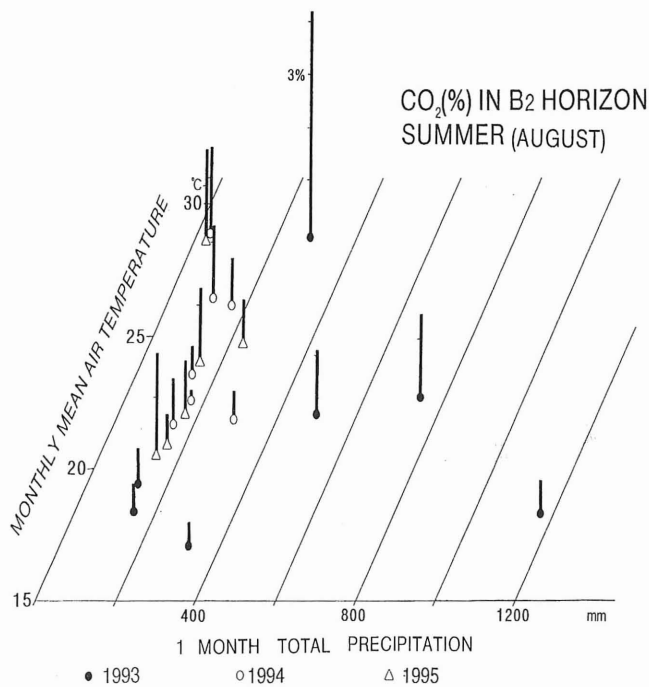


Fig. 5 - Soil CO₂ in the B2 horizon, monthly mean air temperature, and one month precipitation prior to measurement, August 1993-1995.

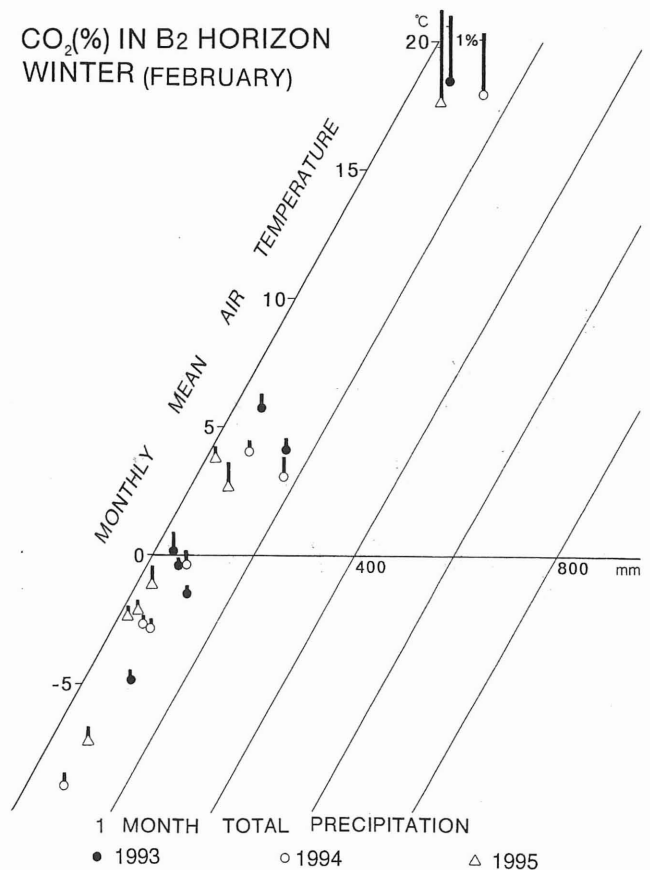


Fig. 6 - Soil CO₂ in the B2 horizon, monthly mean air temperature, and one month precipitation prior to measurement, February 1993-1995.

(4) Soil CO₂ in B2 horizons in almost every season is higher than in A3 horizons. The high CO₂ values measured in Minamidaito Island 2-3 days after precipitation of more than 20 mm suggest that the high CO₂ values also reflect the wet conditions of soils.

(5) The high solution rate of limestone appears to be strongly controlled by CO₂ content in the soil. The solution rates in B2 horizons are always 1.5-5 times higher than the rates in the air.

(6) In summer, when the monthly mean air temperature is over 28°C and one month total precipitation is over 200 mm, soil CO₂ is extremely high.

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