[Articles] Angles of Hillslopes Made of Mudstone in the Southern Part of Okinawa Island

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Angles of Hillslopes Made of Mudstone in the Southern Part of Okinawa Island

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Introduction

The study of slope angles is an important subject in geomorphology. Only recently have some scholars studied slope angles from a dynamic viewpoint and stressed the relationship between slope angles and properties of slope-forming materials (e.g., Lohnes and Handy, 1968; Carson, 1969, 1971, 1975; Carson and Petley, 1970; Rouse, 1975; Matsukura et al., 1984; Mizuno, 1984).

This paper selected hillslopes made of mudstone and will attempt to explain the slope angles from a dynamic viewpoint, which needs to be utilized and developed further in geomorphology.

Study Area

The southern part of Okinawa Island was selected as a study area (Fig. 1). Small hills

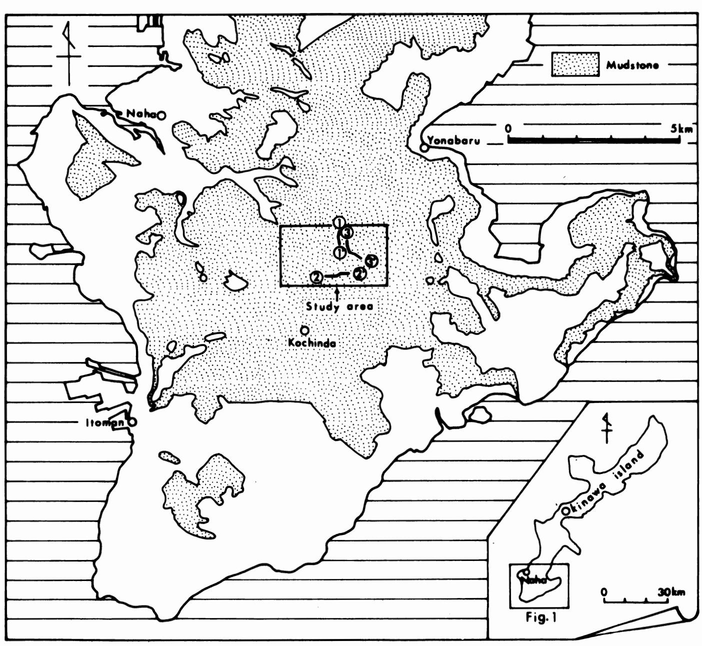

Fig. 1. Location of the study area and the distribution of mudstone (modified after Furukawa et al., 1983). Solid lines show the positions of cross-lines for the slope profiles shown in Fig.2.

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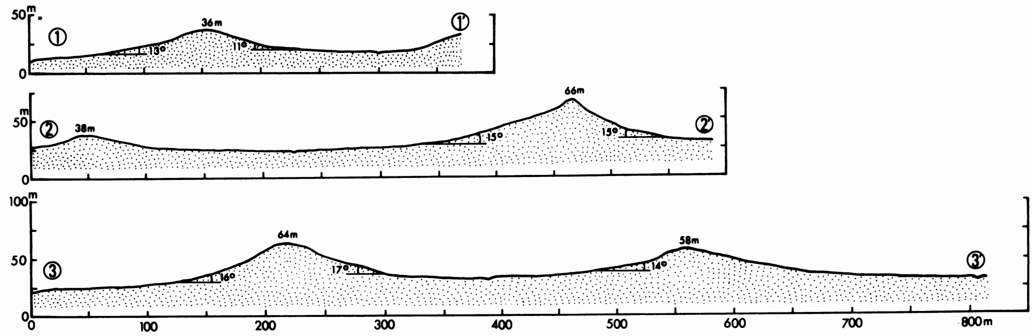

Fig. 2. Slope profiles of the small hills, projected along the solid lines shown in Fig.1.

are well developed in this area and are composed of Tertiary mudstone. The selection was based on the availability of previous data on mudstone properties.

The altitude of the hills is about 30 to 70 m above sea level. The hills are widely dissected by several valleys and have a relative height of several tens meters. The wide valley bottoms are mainly used as sugarcane fields and the hillslopes are covered with *Miscanthus sinensis*.

Tertiary mudstone is exposed in this area (Fig. 1). The mudstone is well bedded and tilted to the southeast. This stone, which was named "Yonabaru Clay Member" of the Shimajiri Formation by MacNeil (1960), is mainly composed of silty clay. The clay ($<5\mu m$) content of the mudstone sampled from near the study area ranges from 42 to 73% (Matsukura and Yatsu, 1982).

Annual precipitation in Naha (Fig. 1), about 7km northwest of the study area, is 2,128mm from 1951−1980 (Japan Meteorological Agency, 1982, p.293). That is relatively high in Japan. Heavy rainfalls are brought by typhoons and the rainy season called "Baiu".

Slope Angles

Using 1:2,500 topographic maps, the profiles of the hillslopes were drawn on 100 measuring lines with about 200-m intervals. The typical slope profiles are shown in Fig.2. The hills have round-top ridges and smooth slopes. Strictly speaking, the hillslopes have concave profiles. However, it can also be seen that the profiles approximate to straight lines.

Considering the straight profiles, average slope angles were measured on 100 slope profiles. The result is shown in Fig.3. This fig-

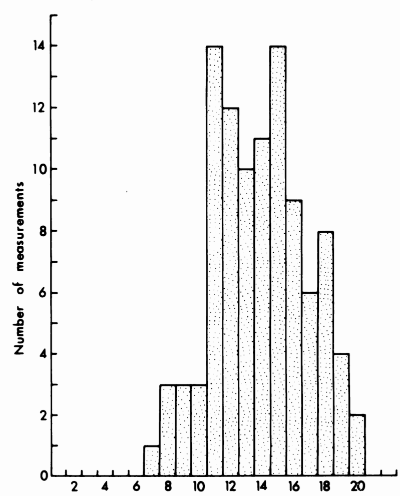

Fig. 3. Frequency distribution of the mudstone hillslope angles.

ure shows that most slope angles concentrate on 11°–16°.

Discussion and Conclusion

Tertiary mudstone has properties of swelling (Matsukura and Yatsu, 1982) which play an important role in landslides (Yatsu, 1966, p.102). Many landslide scars are observed on the hillslopes in the southern part of Okinawa Island. The mudstone slopes are covered with dense vegetation and even on the bare landslide-slopes the vegetation soon recovers. Therefore, sheet and gully erosion have little effect on the retreat of the mudstone slopes. As a corollary, the mudstone slopes are mainly retreated by landslides. Therefore, the angles of the hillslopes are controlled by the angles of landslide planes.

According to Gibo(1978), profiles of landslide planes are circular. However, it can also be seen that the profiles approximate to straight lines. The application of stability analysis of planar failures on an infinite straight-slope would be reasonable for this case. The angle of landslide plane, α, can be determined by the following equation (e.g., Yamaguchi, 1969, p.312):

$$D=\frac{c}{\gamma}\,\frac{\sec^2\alpha}{\tan\alpha-(\gamma_b/\gamma)\tan\phi} \quad\cdots\cdots\cdots\cdots(1)$$

where γ is the unit weight of soil, c the cohesion of soil, ϕ the angle of shearing resistance of soil, γ_b the submerged unit weight of soil and D the landslide depth to be measured vertically. From equation (1), the critical slope angle, α, can be determined when D, γ, c and ϕ are given. When landslides take place, material located on and near the landslide plane would be fully saturated at the time of heavy rainfall. Using the values obtained under saturated conditions by Gibo (1978) : γ=1.8 gf/cm^3, c=0.07 kgf/cm^2, ϕ=17°, we obtain equation (2) from equation (1) for D (in meters):

$$D=0.39\,\frac{\sec^2\alpha}{\tan\alpha-0.14} \quad\cdots\cdots\cdots\cdots\cdots\cdots(2)$$

The relation between D and α is shown by the curve in Fig.4. The upper zone of this curve shows the unstable area, while the lower zone shows the stable area. Depths to the landslide plane range from 3 to 9 m (Gibo, 1978). Two angles, 11° and 16°, are obtained as critical angles for the stable slope in the case of D= 9 m and D= 3 m, respectively. Theoretically the angles of mudstone slopes should be in a range from 11° to 16°. This is in good agreement with the actual slope-angles that mostly range from 11° to 16° (Fig.3).

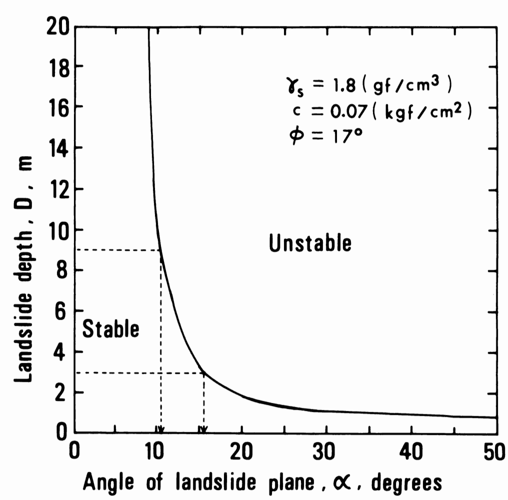

Fig. 4. Relationship between landslide depth, D, and angle of landslide plane, α, for critical state. The curve indicates boundary between stable and unstable slopes.

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References Cited

Carson, M. A. (1969): Models of hillslope development under mass failure. Geogr. Anal., **1**, 76–100.

———(1971): An application of the concept of threshold slopes to the Laramie Mountains, Wyoming. *in* Brunsden, D. ed. : *Slopes form and process*. (Inst. Br. Geogr., Spec. Pub., no.3), Institute of British Geographers, London, 31–47.

———(1975): Threshold and characteristic angles of straight slopes. *in* Yatsu, E., Ward, A. J. and Adams, F. ed.: *Mass Wasting*. (4th Guelph Symposium on Geomorphology), Univ. Guelph, Ontario, 19–34.

Carson, M. A. and Petley, D. J. (1970): The existence of threshold hillslopes in the denudation of the landscape. Trans. Inst. Br. Geogr., **49**, 71–95.

Furukawa, H., Kamiya, K. and Syukumine, R. (1983): Subsurface Geological Map, middle and southern part of Okinawa main land. National Land Agency. (in Japanese)

Gibo, S. (1978): Residual strength and stability of natural slopes in Shimajiri mudstone. Sci. Bull., Coll. Agr., Univ. Ryukyus, **25**, 283–294. (in Japanese with English abstract)

Japan Meteorological Agency (1982): *Climatic table of Japan*, Part 2. 302p. (in Japanese)

Lohnes, R. A. and Handy, R. L. (1968): Slope angles in friable loess. J. Geol., **76**, 247–258.

MacNeil, F. S. (1960): Tertiary and Quaternary Gastropoda of Okinawa. Prof. Paper, U. S. Geol. Surv., **339**, 1–148.

Matsukura, Y. and Yatsu, E.(1982): Wet-dry slaking of Tertiary shale and tuff. Transactions, Japanese Geomorphological Union, **3**, 25–39.

Matsukura, Y., Hayashida, S. and Maekado, A. (1984): Angles of valley-side slope made of "Shirasu" ignimbrite in South Kyushu, Japan. Z. Geomorph. N. F., **28**, 179–191.

Mizuno, K. (1984): Shallow slab slides and slope angles in the Southern part of Chiba Prefecture, Japan. Jour. Japan Landslide Soci., **21**, 33–41. (in Japanese with English abstract)

Rouse, C. W. (1975): Engineering properties and slope form in granular soils. Engineer. Geol., **9**, 221–235.

Yamaguchi, H. (1969): *Soil Mechanics*. Gihodo, Tokyo, 389p. (in Japanese)

Yatsu, E. (1966): *Rock control in geomorphology*. Sozosha, Tokyo, 135p.