Differences in Form and Regolith Characteristics between the Upper and Lower Segments of Slopes in a Watershed in the Omatsuzawa Hills, Northeastern Japan

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Abstract Based on detailed observation of slope form and regolith characteristics, this paper discusses the spatial changes of slope processes and their differences in intensity and frequency on both segments separated by the lower convex break of slope in a small watershed in the Omatsuzawa Hills. The detailed observation of slope morphology and grain-size analysis of regolith reveal that slope processes are prevalent both on the upper and that lower slope segments in the recent past and more frequent and intensive slope processes were prevailed on the lower slope segment. The lower convex break of slope designated as the Postglacial Dissection Front is a result of more active erosion on the segment lower than the break, but it does not mean non-occurrences of slope processes on the segment upper than the break.

Key words Slope form, Breaks of slope, Postglacial Dissection Front, Regolith, Slope processes.

I. Introduction

The previous studies on hillslope classification and chronology in Japan (e.g., Moriya, 1972; Hatano, 1974; Tamura, 1981) have revealed that any cross-section of a valley provides a few convex breaks of slopes and the lower convex break is considered as the boundary between the upper segment which was formed mostly in the colder environment of the last glacial period and the lower segment developed during relatively more humid and warmer postglacial environment. Reports of occurrences of present-day landslides (Miyagi and Tamura, 1987; Hatano and Oyagi,

1988) and the tephrochronological investigations of hillslope micro-landforms (Yanai, 1989; Yoshiki, 1993) have demonstrated that the recent active hillslope processes are concentrated in the lower segment. The lower convex break of slope has been designated by Hatano (1986) as the Postglacial Dissection Front, abbreviated here as PDF.

However, it is worthy to investigate carefully whether the upper segments are free from active slope processes or not. Yoshinaga (1992) has reported that occurrences of active hillslope processes are first controlled by slope gradient irrespective of location in the upper or lower than PDF, although the occurrences are generally more frequent on the steeper slopes lower than

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PDF. Miyagi and Tamura (1988) notified repeated accumulation of colluvial loamy deposits in the Holocene on a head hollow which is located on the upper segment. In order to contribute to the differences in intensity and frequency of slope processes on both parts of the lower convex break of slope, this paper presents the results of detailed observation and measurement of hillslope form and regolith characteristics in a watershed in the Omatsuzawa Hills.

II. Study area

The study site is located in the central part of the Omatsuzawa Hills, about 20 km north of Sendai (Fig. 1). The studied watershed and its surroundings, located in the 70 m high erosion surface (Akojima, 1971), are underlain by semiconsolidated sandstone and siltstone associated with unconsolidated gravel of the Pliocene (Kitamura *et al.*, 1983).

The watershed is a first-order tributary of the River Yoshida. The relative height of the watershed is 40 m. Ground surface of the watershed has not been affected by any artificial disturbance and is covered by secondary deciduous forest composed dominantly of *Quercus serrata*. The lower end of the watershed is artificially cut down to ca. 20 m for extensive industrial site development. Two convex breaks, the upper and the lower, are discernable on the hillslopes in and around the studied watershed (Figs. 1, 2 and 3). The lower convex break is more distinct to divide the upper and lower segments of slope.

III. Description of landform and regolith profiles

Fig. 2 shows the micro landforms of the watershed surveyed with a slope survey equipment TRS-20. The upper segment consists of the crest slope, the upper sideslope, the head hollow, and the head floor. The lower segment of the watershed is composed of the lower sideslope and the channelway with narrow bottomland (Fig. 2). The situation is almost similar to the micro-landform assemblage reported by Tamura (1969, 1974, 1981, 1987). The maximum slope angle is 20° on the upper sideslope, whereas, the lower sideslope shows 38° maximum slope angle. The head floor is sharply incised by the lower sideslope. Just below the lower convex break, the head walls of the bifurcated channelways are obscure (e.g., Figs. 2 and 3), reasonably for the sequential supply of debris from the upper slope segment.

Fig. 3 represents the landform and the locations of soil profiles which are shown in Fig. 2. A thick line in the soil profile indicates the base of colluvial soils (Fig. 3). Colluvial deposition has distinguished from residual soils mainly by the differences in soil colour, structure, texture, as well as stoniness observed in the field and from the grain-size distribution analyzed in the laboratory. Thickness of colluvial layer increases downwards on the crest slope to 49 cm on the head hollow. It decreases a little on the head floor at Loc. 14 in Fig. 3 where transition of former colluvial profile is observed. On the lower sideslope soil profile shows 39 cm thick colluvial loamy soils with conspicuous twofold truncation and burial (e.g., Loc. 15 in Fig. 3).

Fig. 1 Location and geomorphic land classification of the Omatsuzawa Hills.

1. Hilltop gentle slope, 2. Upper sideslope, 3. Head hollow, 4. Lower sideslope,
5. Spur, 6. Valley floor, 7. Upper convex break of slope, 8. Lower convex break
- of slope, 9. 1st order stream, 10. 2nd order stream, 11. 3rd order stream,
12. 4th order stream, 13. Study site

Fig. 2 Micro-scale landforms in the Omatsuzawa watershed.

1. Crest, 2. Upper sideslope, 3. Head hollow, 4. Head floor, 5. Lower sideslope,
6. Channelway and bottomland, 7. Divide, 8. Distinct convex break of slope,
9. Indistinct convex break of slope, 10. Concave break of slope,
11. Boundary of head hollow and head floor, 12. Slope direction and slope angle,
13. Soil pit, 14. Slope profile.

On the upper slope segment neither any apparent landslide scar nor any clear discontinuity in soil morphology are observed to estimate prominent intervention of slope processes. But, thickness and texture of regolith, as well as the concave topographic form, suggest that the head hollow has sustained by repeated depositional and erosional events. Differences in permeability between the upper colluvial layer and the lower residual soils is demarcated by the occurrences of

throughflow along the bottom of the colluvial layer. The soil pit dug on the head hollow (Loc. 13) was gradually filled up by water seeped away from the colluvial B horizon, whereas the pit on the upper portion of the upper sideslope (e.g., Loc. 12 in Fig. 3) was remained dry on 15th May, 1993, after a heavy rainstorm in preceding two days. The phenomena suggests the colluvial characteristics of regolith on the upper slope segment.

Fig. 3 Landform and soil profiles on each micro-scale landform units in the Omatsuzawa watershed.

Sampling depth in each soil horizon is indicated by an asterisk.

The locations of sampling sites are shown by the same numbers in Fig. 2.

"c": very compact, c: compact, (C): slightly compact, (1): slightly loose, 1: loose, "1": very loose, w: wet, m: moist, (R): less weathered bedrock.

Fig. 4 Grain-size distribution of soil profiles on different micro-scale landform units, Omatsuzawa watershed.

1. Clay, 2. Silt, 3. Fine sand, 4. Medium sand, 5. Coarse sand, 6. Small gravel (2 mm-2 cm), 7. Large gravel (>2 cm)

A dashed line denotes sampling depth in each soil horizon.

Table 1 Grain-size analysis and field descriptions of soil profiles, Omatsuzawa watershed

Loc. No.	Position/Horizon	CLAY	SILT	SAND			GRAVEL		Colour	Texture	Structure	Boundary	Depth (cm)
		Clay %	Silt %	Fine sand %	Medium sand %	Course sand %	Small gravel % (2 mm-2 cm)	Large gravel % > 2 cm					
11	Crest A1	20.15	32.03	23.93	9.29	9.13	5.47 ⁽¹⁾	0	7.5YR 3/3	HL	wc	cs	0-5
	A3	16.33	29.38	21.38	14.60	12.24	6.08 ⁽²⁾	0	10YR 3/3	SL	sb	cs	5-10
	B	9.57	19.17	18.95	10.17	25.05	15.59 ⁽²⁾	1.51	10YR 4/4	SL	sb	d	10-28
	C	11.35	20.18	20.68	12.02	21.30	14.46 ⁽²⁾	0	10YR 5/6	SL	m	—	28~50
12	Upper sideslope A1	20.71	34.09	22.19	9.69	8.73	4.59 ⁽¹⁾	0	7.5YR 3/3	HL	wc	d	0-3.5
	A3	19.51	30.72	20.50	9.12	7.94	12.22 ⁽¹⁾	0	7.5YR 4/3	L	wsb	d	3.5-13.0
	B1	18.10	31.83	22.30	9.60	12.79	5.38 ^(1,2)	0	7.5YR 4/4	SL	sb	cs	13.0-25.0
	IIB2	15.58	29.33	23.73	11.46	12.81	6.24 ^(1,2)	0.86	7.5YR 4/4	LS	wsb	d	25.0-45.0
	IIC	15.49	28.19	23.80	13.07	13.68	5.78 ^(1,2)	0	7.5YR 4/6	LS	wsb	—	45.0~97/100
13	Head hollow A1	20.13	32.35	20.80	7.45	5.23	13.05 ⁽¹⁾	0	7.5YR 2/3	HL	wc	cw	0-4
	A3	19.06	31.99	21.97	9.50	8.47	7.09 ⁽¹⁾	1.92	7.5YR 3/3	L	sb	as	4-26
	B	21.97	27.49	24.98	11.75	11.34	2.58 ^(1,2,3)	0	7.5YR 4/4	CL	wsb	cs	26-49
	IIC	15.57	29.65	23.28	11.69	10.51	9.29 ^(1,2)	0	10YR 4/6	L	wsb	—	49-100
14	Head floor A1	25.98	36.51	18.51	8.30	6.48	4.21 ⁽¹⁾	0	7.5YR 3/2	HSL	wsb	cs	0-7
	A3	23.55	35.98	20.36	8.82	8.31	2.99 ⁽¹⁾	0	7.5YR 4/3	SL	wsb	d	7-14
	B1	17.62	37.32	18.58	8.37	11.30	16.81 ^(1,2,3)	0	10YR 5/6	LS	sb	cs	14-22
	IIB2	12.32	20.28	18.69	13.79	20.66	12.63 ^(1,2)	1.63	7.5YR 5/6	SCL	m	d	22-42
	IIC	34.08	35.23	10.41	4.83	6.40	6.88 ^(1,3)	2.17	7.5YR 5/6	CL	m	—	42-64
15	Lower sideslope A	19.21	33.25	15.52	5.66	10.34	15.97 ⁽¹⁾	0	7.5YR 3/2	HSL	wc	cw	0-5 0-9
	B	12.60	22.27	16.06	8.00	9.93	26.77 ^(2,3)	4.35	7.5YR 4/4	L	wsb	cw	5-20 9-27
	IIA	20.81	33.98	18.79	8.45	11.28	6.68 ^(1,3)	0	7.5YR 3/4	HSL	wc	cw	20-26 27-32
	IIB	19.61	34.34	17.69	7.95	11.37	9.03 ^(1,2)	0	10YR 5/4	SL	sb	d	26-36 32-39
	IIC	14.79	21.89	18.01	9.09	14.44	19.05 ^(1,2)	2.74	10YR 5/6	SL	wsb	—	36/39~48

Weathering state of gravel is indicated by the number in parenthesis as follows:

(1): Unweathered, (2): Slightly weathered, (3): Highly weathered

Texture: HL: Humic loam, L: Loam, SL: Sandy loam, LS: Loamy sand, CL: Clayey loam, HSL: Humic sandy loam, SCL: Sandy clayey loam

Structure: wc: Weak crumbly, sb: Subangular blocky, wsb: Weak subangular blocky, m: Massive

Boundary: cs: Clear smooth, cw: Clear wavy, as: Abrupt smooth, d: Diffuse

IV. Results of grain-size analysis

Soil samples were collected from each horizon of soil profiles. The location of sampling sites are shown in Fig. 3. The grain-size analysis is accomplished by pipette method for extraction of clay and fine silt and by sieving for segregating particles coarser than fine silt. The data of grain-size distribution (e.g. Fig. 4 and Table 1) emphasize that higher content of sand and silt with some differences in gravel and clay content is inherited from the parent rock which is composed of semiconsolidated sandstone, siltstone and unconsolidated gravel of the Pliocene.

On the crest slope, at Loc. 11 in Fig. 4, sequential clay and gravel distribution in the upper horizons implies considerable soil profile development which has not been disturbed by recent slope processes. But, at Loc. 11, remarkable decline of coarse fragments in A3 horizon than the horizon below (e.g., Fig. 4 and Table 1) seems to be the effect of creeping. Similar distribution of size-class and weathering state of gravels of similar lithology in different horizons of the soil profile No. 12 on the upper sideslope (e.g., Fig. 4, Table 1) lead to the interpretation that sediments have been periodically and recurrently provided by creeping from the crest slope. Apparent increase of coarse sediments at a depth of 13 cm in A3 horizon (Figs. 3 and 4) than the horizon below at Loc. 12 reflects the accumulation by creeping.

Segregation of coarse sands and granules, specially quartz grains, at the bottom of B horizon on the head hollow (e.g., Loc. 13 in Fig. 3) and marked decrease in gravel content in the same horizon (Fig. 4) can be described as a consequence

of shallow landslide which was later followed by sheetwash to segregate coarse grains on the exposed scar surface. On the head floor, just above the lower convex break of slope (e.g., at Loc. 14 in Figs. 3, 4 and Table 1), weathering and pedogenesis is prominent in clay rich IIIC horizon in comparison with IIB2 horizon. Furthermore, presence of many bright brown (7.5 YR 5/6) and dull yellowish orange (10 YR 7/2) mottles in IIIC horizon (Fig. 3) refers to the effect of long-term water table fluctuation. In context to the above stated evidence, highly clayey IIIC horizon may have been developed by rapid pedogenesis during upward flux of ground water during wet-up periods for longer exposure of the surface. The sandy and gravelly IIB horizon with lack of finer sediments may have been transported by landslide occurred probably on the surrounding upper side-slope. The deposition of relatively less weathered B1 horizon which is characterized by higher concentration of small gravels. Clear smooth bottom of the horizon was formed by shallow landslide from the head hollow, following to the deposition of IIB2 horizon (e.g., at Loc. 14 in Fig. 4).

The abrupt contrast in grain-size distribution in different soil horizons and clear discontinuity in boundaries at Loc. 15 show the occurrences of some sort of accelerated and intense slope processes. The evidence of partial removal of humic IIA horizon at the location has undoubtedly been promoted by rapid occurrences of debris slide. The higher concentration of gravel in B horizon at Loc. 15 (Fig. 4, Table 1) with noticeable decrease in clay and silt seems to be the consequence of reworked addition of material by creep-

ing or tree uprooting on the slope behind. Most of the observed horizons on the lower sideslope (e.g., at Loc. 15 in Fig. 3, Table 1) possess irregular boundaries due to recurrent incidents of slope processes.

V. Discussion

Observation of slope form and soil profiles and grain-size analysis of each soil horizon exhibit that the Omatsuzawa watershed has experienced both sporadic and frequent prevalence of slow and accelerated slope processes. Abruptness in horizon boundaries and textural discontinuity in the horizons have proved that the lower slope segment has been affected by several times of shallow slide type mass-movements and by repeated occurrences of creeping or movements of soils implicated in roots of fallen trees. Whereas, the increasing trend of clay content in the upper horizons on the upper slope segment reflects relatively stable soil profile development in the recent past. On the other hand, significant concentration of gravel in upper horizons of some soil profiles on the upper slope segment is considered as a consequence of creeping or tree throw. Apart from it, evidences of intermittent deposition in the head hollow and head floor show the alternating filling and removal of soils on the upper slope segment.

Most of the deposits contain relatively fresh or slightly weathered gravels. On the downslope of the upper slope segment relatively high weathered gravels are concentrated at the bottom of colluvium as indication of higher rate of pedogenesis in the topographic position. In contrast, relatively high weathered gravels are overlain by rela-

tively less weathered gravels on the lower slope segment (e.g., at Loc. 15 in Table 1). The fact signifies the removal of gravels on the upper horizons of the lower segment by most recent processes after getting considerable weathering effect.

VI. Conclusion

The steep slope gradient and marked stratigraphic discontinuity of slope deposits on the lower slope segment in the Omatsuzawa watershed is a result of frequent and erosive slope processes in the recent past, which also supports the emergence of steep lower sideslope and the distinct character of lower convex break of slope in the Omatsuzawa Hills. It incorporates the concept of PDF (Hatano, 1986). Whereas, the detailed soil profile observation and grain-size analysis indicate the occurrences of slope processes both on the upper and lower slope segments separated by the lower convex break of slope. Nevertheless, the upper slope segment with gentle slope and gradual soil profile development confirms relatively less interference of slope processes in the recent past. Thus in conclusion it can be said that both the upper and lower slope segments were disturbed by slope processes, but their intensity and frequency were more concentrated on the lower slope segment of the Omatsuzawa watershed in the recent past.

Acknowledgment

The author expresses sincere gratitude to Prof. T. Tamura of Tohoku University for his constant advice and valuable comments. I am deeply thankful to Associate Professor Hideaki Matsumoto for his help in selection of the study site. My heartfelt thanks

should be paid to Shuichiro Yoshinaga of Forestry and Forest products Research Institute for his important advice. Thanks are also due to Dr. Kiyoshi Saijo, Naoto Koiwa, Takeya Yoshiki, Takahisa Furuchi, and Hiroshi Nakura for their assistance during the course of field survey. I convey my thanks to Dr. Tsutomu Satoh, Institute of Genetic Ecology, Tohoku University for his guidance in grain-size analysis.

(Accepted February 24, 1995)

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(* in Japanese, ** in Japanese with English abstract)

宮城県大松沢丘陵における斜面の微地形と表層物質

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