History of Morphogenetic Environments of the Kitakami Mountains, Northeastern Japan, in the Late Quaternary

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Abstract History of morphogenetic environment in the late Quaternary is investigated in the central part of the Kitakami Mountains with reference to the changes of debris movement system dominant on respective geomorphic position in each time.

Debris production and transport by solifluction under cold climate became dominant three times in the late Quaternary, their is a time older than the Last Interglacial (Before 100 ka.), during the early Last Glacial (around 50 ka.) and the late Last Glacial (a few thousand before 30 ka. to 10 ka.). In these times the gentle slopes on the summits and the smooth crest slopes were formed as denudational slopes. Debris provided from these slopes were transported and accumulated in the valley heads and on the foot parts of slopes, forming the upper head-hollow slopes and the piedmont gentle slopes. In the upstream areas debris provided from the side slopes was transported by slope wash and debris flow, and formed the fan-like gentle slopes. Filltop terrace surfaces were formed by river bed aggradation in the early and the late Last Glacial.

During the Holocene dominant slope movement processes have been landslides and debris flows, which were more active in the early Holocene (10-5 ka.). Debris provided by landslides which formed the lower head-hollow slopes was transported by landslides and debris flows and settled to form the talus and the alluvial cones.

This study has revealed the following relationships between each morphogenetic stages also. Clayey soils produced by chemical weathering in the Last Interglacial activated slope movements as matrix for solifluction in the subseguent early Last Glacial. Landslides in the Holocene were conditioned by the debris accumulation on mountain slopes during the preceding Last Glacial.

Key words: morphogenetic environment, debris movement system, late Quaternary, Kitakami Mountains

1 Introduction

Quaternary climatic changes greatly affected land surface development in Japan by altering morphogenetic processes, sediment yield, and river water discharge. Recent historical studies of mountain slope formation have indicated changes in morphogenetic processes of slopes formation (Higaki 1987, Shimizu 1992) as well as

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variations in debris yield from mountain slopes in response to the late Quaternary climatic change (Ono and Hirakawa 1975 ; Miyagi and Nakayama 1984). Chronological studies of river terraces and alluvial fan formation have also supported the latter hypothesis (Toyoshima 1984 ; Saito 1978 ; Watanabe 1991). Recently, tephrochronological studies of slope evolution have been conducted to better understanding processes and formative ages of slopes (Tamura and Miura 1971 ; Higaki 1987 ; Yanai 1989 ; Nomura and Tanaka 1989).

Morphogenetic development of mountain slopes affects those of rivers and plains by supplying debris to rivers and streams in a drainage basin. Individual mountain slopes may have different functions in debris movement such as production, transportation, and deposition. However, changes in the debris movement system, which included debris production, movement, and accumulation, and which controlled land surface development in mountain areas relative to late Quaternary climatic changes, have scarcely been recognized through the chronology of various slopes and river landforms in mountainous terrains. Yamamoto (1987) and Higaki (1988) demonstrated the time correspondence between piedmont gentle slope formation and river terrace deposition. Oguchi (1988) discussed the total land surface development in a catchment area of the Matsumoto Basin in central Japan.

This study will examine total landsurface development in a mountainous area, noting changes in debris movement systems from mountain slopes to rivers in the late Quaternary. The relationship between adjacent stages of landsurface development will also be examined. The study area is the central part of the Kitakami Mountains in northeast Japan, which is mostly composed of low relief areas and contains slope deposits sufficient to discuss the morphogenetic processes of previous stages. The use of marker tephras made a tephrochronological approach possible (Higaki 1987).

2 Study area

The Kitakami Mountains are located in northern Honshu Island. The highest point is Mt. Hayachine (1,914 m). The inland area of the Kitakami Mountains is mostly composed of undulating uplands of 600-1,300 m asl., which are believed to have formed as peneplains (Nakamura 1963) (Fig. 1). The eastern area is composed of highly dissected mountains with relief of 600-900 m, and river terraces of several levels exist along the Hei and the Omoto rivers which flow into the Pacific Ocean (Higaki 1988).

The lithology of the western part of the study area is composed of Paleozoic to Mesozoic sedimentary rocks, metamorphic rocks, and partly ultra-basic rocks. Granitic rocks are exposed in the eastern part.

Tephras as time markers distributed in the study area mostly correspond to the

Fig. 1 Summit level map of the Kitakami Mountains.

tephra sequences studied by Ogami and Doi (1978, 1980) in the upper lowland area along the Kitakami River. The marker tephras are, in reverse chronological order (Fig. 2) : The Akka Volcanic Ash (Ak) (5,000 yr B.P.) ; The Wakare Brown Weathered Volcanic Ash (WL) (10,000-12,000 yr B.P.) ; The Yanagisawa Pumice (YP) (11,000-12,000 yr B.P.) ; The Koiwai Pumice (KP) (13,000 yr B.P.) ; The Hachinohe Pumice (HPt) (13,000 yr B.P.) ; The Takizawa-1 Scoria ; (T1S) (around 20,000 yr B.P.) ; The Takizawa-2 Scoria (T2S) (around 30,000 yr B.P.) ; The Oide Black Ash (OBA) (30,000-40,000 yr

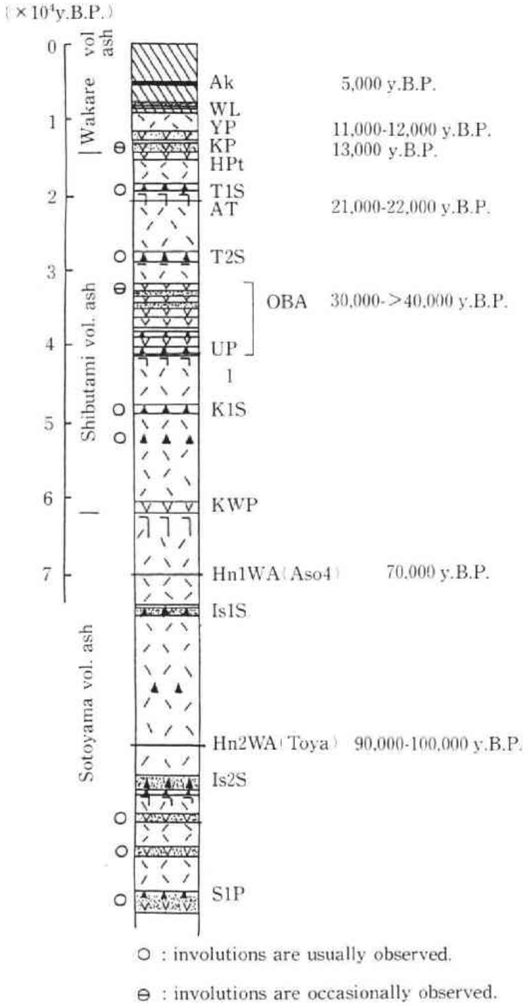


Fig. 2 Tephra stratigraphy in the study area in the northern Kitakami Lowland area. (Modified by Higaki 1987)

B.P.); The Kaganai-1 Scoria (K1S) (around 50,000 yr B.P.); The Ishihana-1 Scoria (Is1S) (between 90,000 and 70,000 yr B.P.); The Ishihana-2 Scoria (Is2S) (before 90,000 yr B.P.); and the Shijushida-1 Pumice; (S1P) (after Higaki 1987). HPt (Doi and Arai 1986) corresponds to WP (Higaki 1987). Estimates for the ages of Is1S and Is2S fall were based on those from the Toya fall (Machida *et al.* 1987). Most tephras originated from the Iwate or Akita-Komagatake volcanoes.

3 Slopes and river terraces in the Central Kitakami Mountains

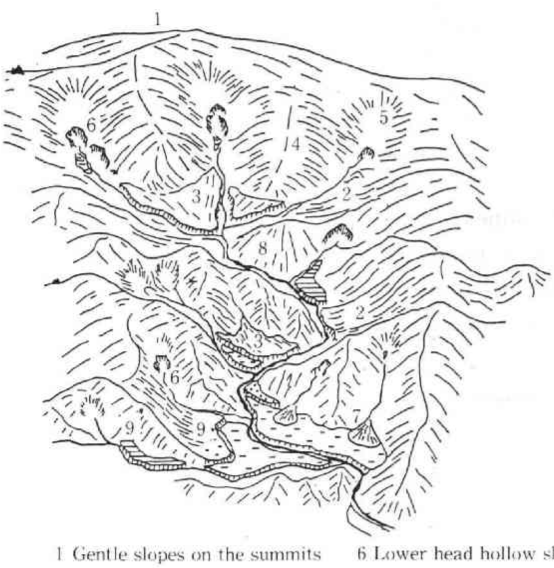
Higaki (1987) classified eight units (categories) of slopes in the central Kitakami Mountains, by their geomorphic position.

In the eastern section, river terraces of four or five levels, piedmont gentle slopes, alluvial cone, and talus were recognized (Higaki 1988). This study has morphologically classified the landforms of the central Kitakami Mountains into nine categories : 1) Gentle slopes on the summits, 2) Piedmont gentle slopes, 3) Fan-like gentle slopes, 4) Smooth crest slopes, 5) Higher head hollow slopes, 6) Lower head hollow slopes, 7) Talus and Alluvial cones, 8) Miscellaneous slopes, and 9) River terraces (Fig. 3). Typical landforms of the inland area are shown in Fig. 4.

The landforms and deposits of each category are described as follows :

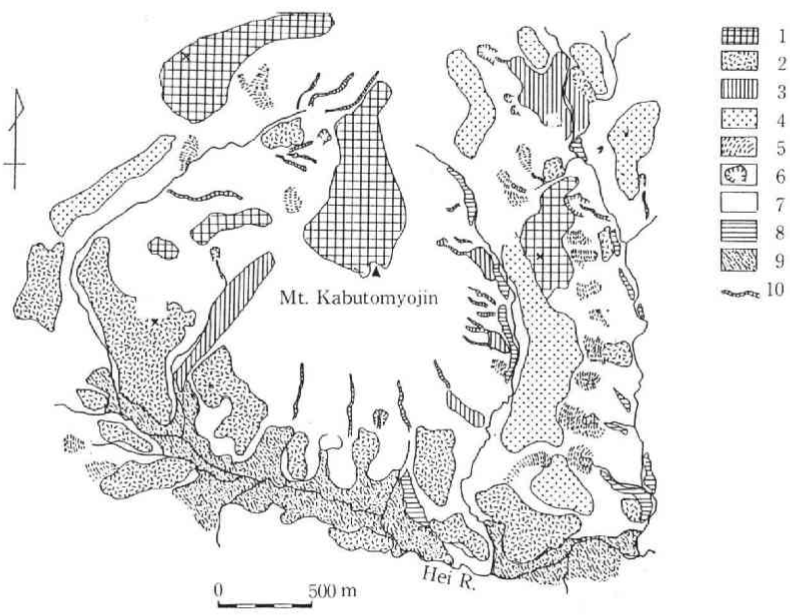
1) Gentle slopes on the summits

They are smooth gentle slopes of denudational origin on the summit with a gradient less than 15°. Thin breccia layers or clayey loams with rubble layers are covered with the tephras of WL, KP, YP. Three distinct weathered slope deposits have been recognized.



1 Gentle slopes on the summits
2 Piedmont gentle slopes
3 Fan-like gentle slopes
4 Smooth crest slopes
5 Upper head hollow slopes
6 Lower head hollow slopes
7 Talus and alluvial cones
8 Other slopes
9 River terraces

Fig. 3 Morphological classifications in the central Kitakami Mountains.



1 Gentle slopes on the summits
2 Piedmont gentle slopes
3 Fan-like gentle slopes
4 Smooth crest slopes
5 Upper head hollow slopes
6 Lower head hollow slopes
7 Other slopes
8 River terrace (F-3)
9 River terrace (S-1)
10 Gullies

Fig. 4 Morphological map of the Kuzakai Highland.
(Modified by Higaki 1987)

2) Piedmont gentle slopes

They are smooth piedmont gentle slopes of depositional or a part denudational origin with a gradient less than 15°.

The slopes are composed of similar deposits as the gentle slopes on the summits.

3) Fan-like gentle slopes

They are smooth gentle slopes of depositional origin with a gradient less than 15° formed at valley mouths or junctions. Subangular gravel layers usually covered with WL have been recognized.

4) Smooth crest slopes

They are smooth convex slopes of denudational origin on the crest. Thin rubble layers are covered with WL or breccia-rich WL on the Unit.

5) Higher head hollow slopes

They are shallow hollow slopes of more than 4×10^2 m^2 in scale developed at valley heads. Rubble layers covered with WL or breccia-rich WL are deposited, burying the hollow features of bed rock.

6) Lower head hollow slopes

They are hollow slopes smaller than the higher head hollow slopes developing at first order valley heads. Non-sorted promiscious rubble or boulder deposits intercalate Ak.

7) Talus and Alluvial cone

They are depositional slopes steeper than piedmont or fan-like gentle slopes at slope foot or valley mouth.

8) Miscellaneous slopes

They are slopes other than those mentioned above. There are various cases in stratigraphy between breccia layer and tephras.

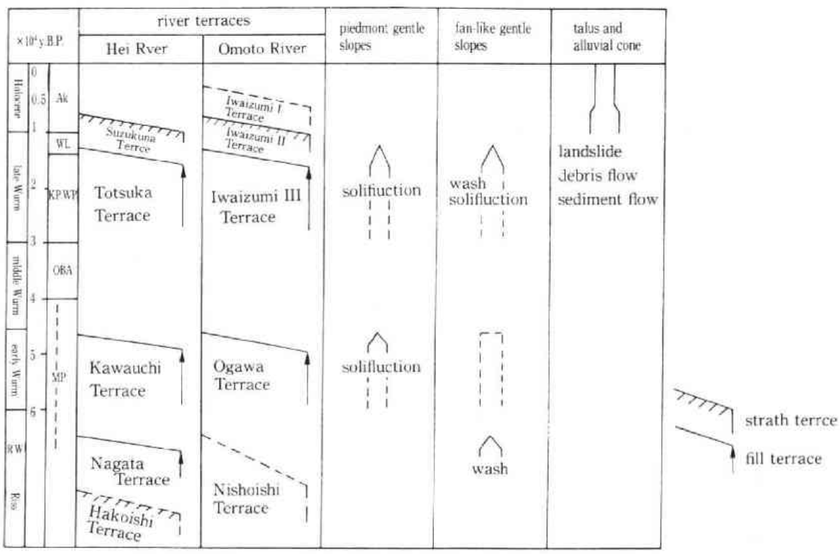


Fig. 5 The chronology of river terraces, piedmont gentle slopes and fan-like gentle slopes. (Higaki 1988)
(Nagata terrace : F-1 terrace, Kawauchi and Ogawa Terraces : F-2 terrace, Totsuka and Iwaizumi III Terraces : F-3 Terrace, Suzukuna and Iwaizumi II Terraces : S-1 Terrace, Iwaizumi I Terrace : S-2 Terrace)

9) River terraces

Two fill terraces whose deposits are more than 10 m thick are distributed in the Hei and Omoto river basins. Other highest fill terraces are distributed along the Hei River. The lowest well-developed river terrace is a strath terrace, which is widely distributed and often covered with Ak.

The chronology of river terraces is shown in Fig. 5. (Higaki 1988) Here, three fill terraces, referred to as F-1 terrace, F-2 terrace, and F-3 terrace, are arranged in chronological order. Fill-3 terraces are usually distributed along branch valleys. Well-developed terraces are referred to as S-1 terraces, while fragmental river terraces, referred to here as S-2 terraces, have been observed at levels lower than S-1 terraces.

4 Periods and processes of slopes and river terrace formation

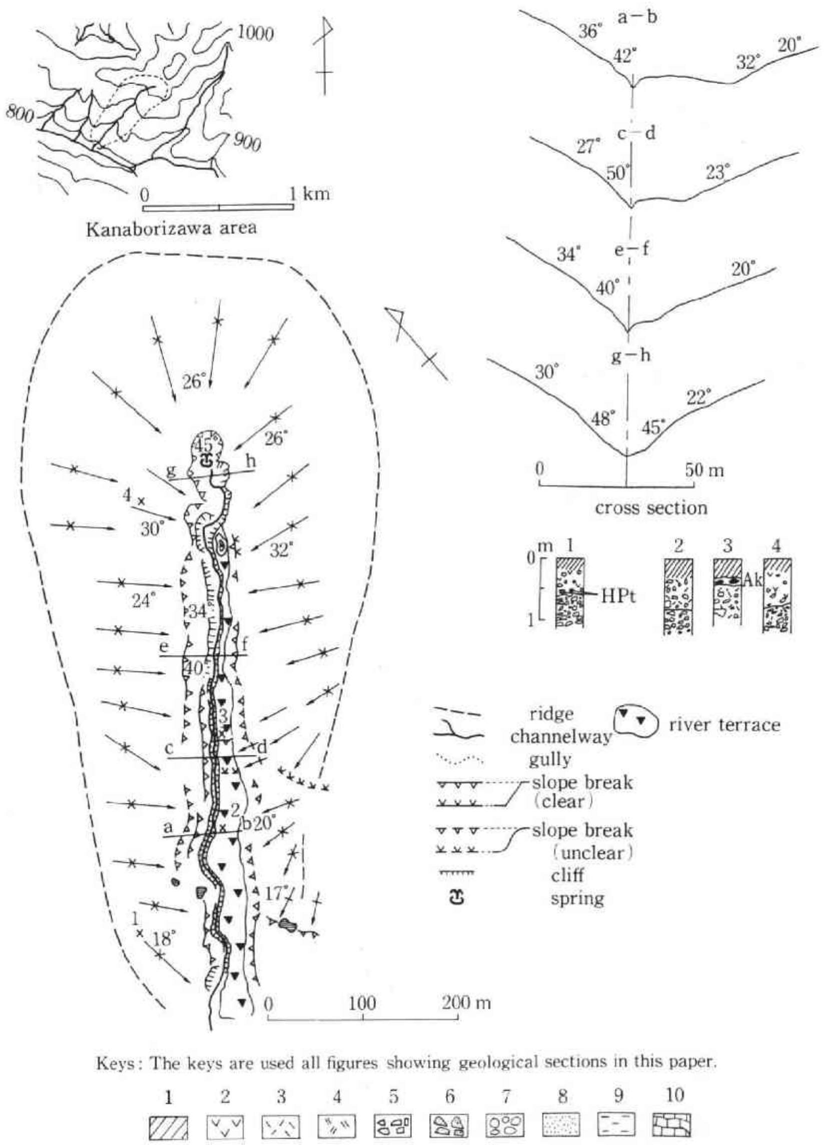
The changes in morphogenetic debris movement systems, as well as morphogenetic paleo-environments, can be understood through the periods and formative processes of each landform unit

4.1. Slopes and river terraces formed during the Last Glacial

Higaki (1987) described the periods of mass movement and slope formation in the inland area of the central Kitakami Mountains applying tephrochlonological methods to slope deposits.

The gentle slopes on the summits and the smooth crest slopes were formed by debris production through frost shattering and solifluction in cold climates during the Last Glacial. The piedmont gentle slopes and the upper head hollow slopes were chiefly formed by deposition of debris transported by solifluction. There were three stages in the formation of the gentle slopes on the summits and the piedmont gentle slopes under periglacial conditions, two of which are correlated to the early Last Glacial (around 50 ka) and the late Last Glacial (from several thousands before 30 ka to 13-10 ka), respectively based on the comparison of involutions in the Kitakami Lowland area. The other stage was dated before the Last Interglacial Period. The fan-like gentle slopes were created chiefly by slope wash or earth flow in the early Last Glacial and partly by solifluction as well as by slope wash or earth flow in the late Last Glacial, in much the same formatrive stages as the piedmont gentle slopes.

In the eastern Kitakami Mountains, river terraces and gentle slopes were chronologically studied (Higaki 1988). F-2 river terrace surfaces were completed older than 40 ka in the early Last Glacial, corresponding to the formative period of piedmont gentle slopes. F-3 terrace surfaces, piedmont gentle slopes and fan-like gentle slopes were completed around 13 ka in the latest of the Last Glacial.



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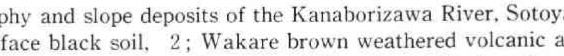


Fig. 6 Topography and slope deposits of the Kanaborizawa River, Sotoyama Highland.
Key: 1; surface black soil, 2; Wakare brown weathered volcanic ash, 3; weathered clayey ash, 4; pumice, 5; rubble, 6; rubble (weathered), 7; fluvial gravel, 8; Sand, 9; clay, 10; bed rock.

The deposition of F-1 terraces is believed to have occurred at the same time as the highest fan-like gentle slope formation during or before the Last Interglacial.

4.2. Slopes and river terraces formed in the Post Glacial Period

The lower head hollow slopes were formed by lanslides, and the talus and the alluvial cones were formed by debris flow or sediment flow in the Post-glacial period probably due to an increase in precipitation since the end of the Last Glacial.

This section will discuss the main formative periods of the lower head hollow slopes, the talus, and the alluvial cones.

4.2.1. Kanaborizawa area

There is a lower head hollow slope with length of 40 m and width of 50 m at the head of the Kanaborizawa torrent in the Sotoyama Highland (Fig. 6). Surrounding valley slopes are composed of the smooth crest and flank slopes with gradients of 20-30°. The sides of lower head hollow slopes of 45-50° in gradient are surrounded by clear slope breaks. A spring, the source of flowing water in the valley, is found at the bottom of the lower head hollow slope. A river terrace surface of 14° in gradient exists along the valley.

The surrounding slopes around the lower head hollow slope are composed of ruble layers of shale covered with rubbble-mixed WL or HPt, but WL has not been observed on the lower head hollow slope. Breccia with loamy matrix covered with Ak forms the river terrace which is continuous from the lower head hollow slope (Fig. 6).

The shape and deposits of the lower head hollow slopes are similar to those of the head hollow in hilly lands which are thought to have been formed by landslides

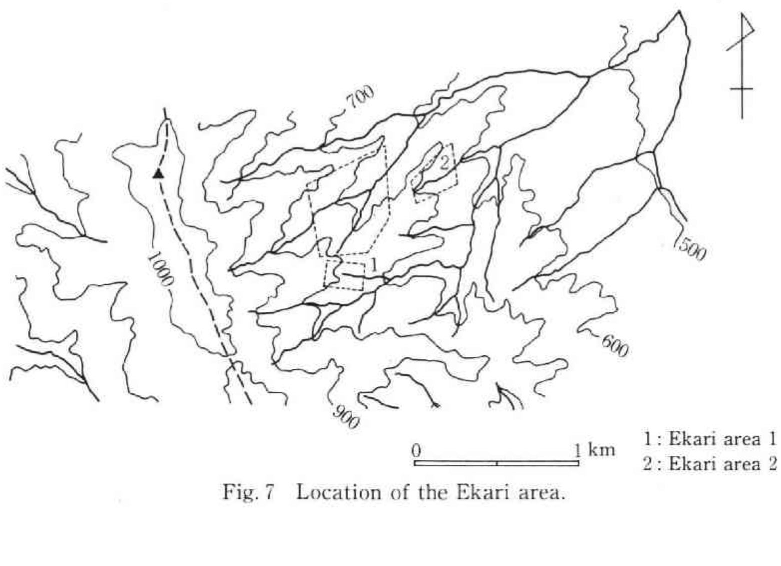


Fig. 7 Location of the Ekari area.

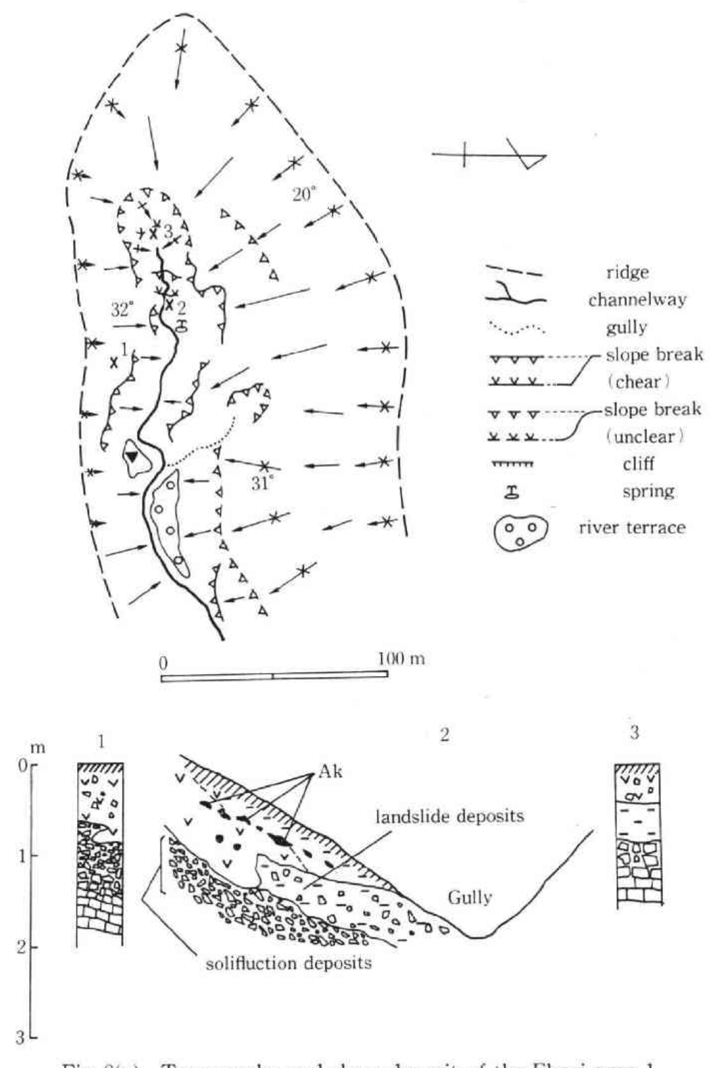


Fig. 8(a) Topography and slope deposit of the Ekari area 1.

(Tamura 1974). The lower head hollow slopes are also believed to have been formed by landslides in the time between WL and Ak fall in the Post-glacial period. The river terrace along the water course was formed by debris flow originated in the landslides, because the gradient of the water course is more than 10°, the lower limit of debris flow occurrence (Ikeya 1980).

4.2.2 Ekari area

The formative ages of the lower head hollow slopes have been examined at Ekari

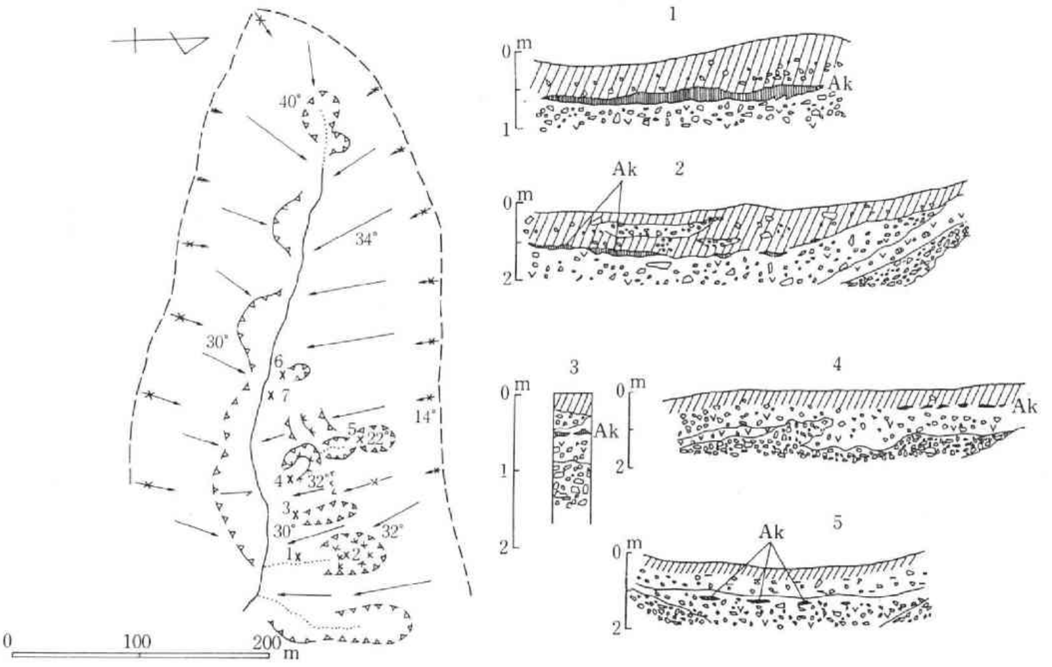


Fig. 8(b) Topography and slope deposit of the Ekari area 2.

area in Kuzumaki Town where Ak is widely distributed. The study area is mostly composed of the smooth crest slopes and flank slopes of gradient 10-35°, which are dissected by small valleys. The geology of this area is composed of shale and chert. Figs. 7 and 8 depict two valley watersheds in Ekari area.

In the first area (Ekari 1 area) there are two lower head hollow slopes of different levels at the valley head (Fig. 8a). A frost-shattered rubble layer covered with WL containing rubble a little reaches from the flank slopes to the lower head hollow slope of the lower level. At the bottom of the lower head hollow slope rubble-rich clayey deposits are underlain by the frost-shattered solifluction deposits. Ak covers the rubble rich clay layer.

In the second area (Ekari 2 area) several lower head hollow slopes are observed in the flank slopes with gradient of 30-34° (Fig. 8b). The gradient of the lower head hollows is 35-50° at the side and 20° at the bottom.

Rubble with clayey matrix is covered with Ak at the lower head hollow slopes in this area. Rubble layers covered by Ak at the lower head hollow are less oriented than those of flank slopes (Fig. 9). The ratio of sorting in diameters of rubble layer is smaller in the deposits of the lower head hollow than in those of flank slopes. These facts indicate that rubble layers with clay matrix were originated in landslides which

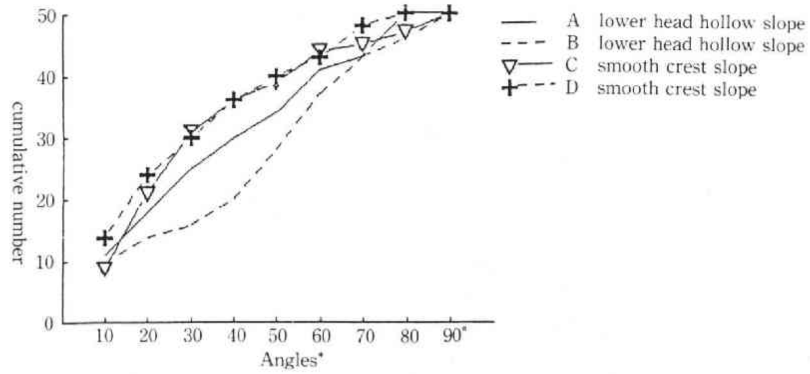


Fig. 9 The orientation of gravels in the slope deposits.
* Angles between long axis of gravels and the direction of slope inclination.

formed the lower head hollow slopes. There is a rubble layer with black humic soil matrix above Ak, but the width and thickness of this layer are smaller than the layer below Ak in Locs. 2, 4, 5 (Fig. 8b). This means that the lower head hollow slopes are mainly formed in the time between WL and Ak fall (around 10,000-5,000 yr B.P.), and surface slope failure, which barely changed the form of the lower head hollow, occurred on the side slopes of the lower head hollow after Ak fall.

4.2.3. The Eastern Kitakami Mountains

Numerous talus or alluvial cones have developed at the foot of flank slopes steeper than 30° in gradient or on S-1 river terrace surfaces of rivers with large drainage basins, especially in the eastern part of the Kitakami Mountains.

The talus and the alluvial cones in the inland area are believed to have been formed after 10 ka by slope failures and debris flows moved from the posterior slopes (Higaki 1987). The formative ages of the talus and alluvial cones have been investigated in the Hei and Omoto River Basins where Ak is widely distributed (Fig. 10. 12).

There is a talus of 18° in gradient behind the F-3 Teracce surface along the Natuya River (Loc. 1). Uneven flank slopes composed of shale are situated behind the talus.

A rubble layer with clayey matrix 1.5 m thick is deposited above KP and Ak is found 0.2-0.3 m below the surface at the upper part of the talus (Fig. 11). This stratigraphy indicates that the talus formed within the late Last Glacial before 13 ka.

At Loc. 2, granite boulders form the talus at the flank slopes of 30-45° in gradient which has partly free face composed of granite (Fig. 11). The talus deposits are distinguished into two parts by facies and stratigraphy. Boulder layers with a little matrix are overlain by Ak in front of the free face or flank slopes, and clayey rubble

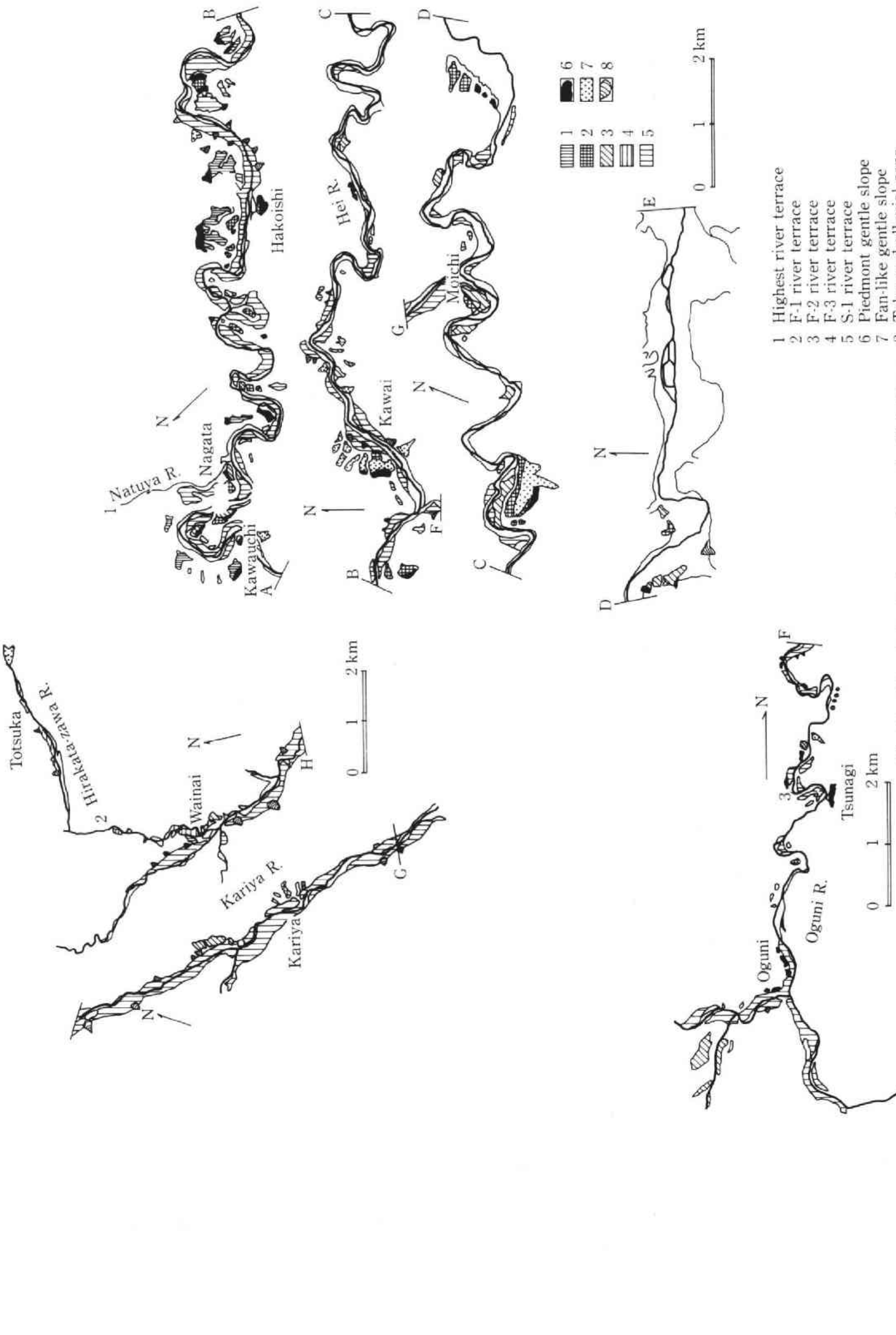


Fig. 10 Morphological map along the Hei River.

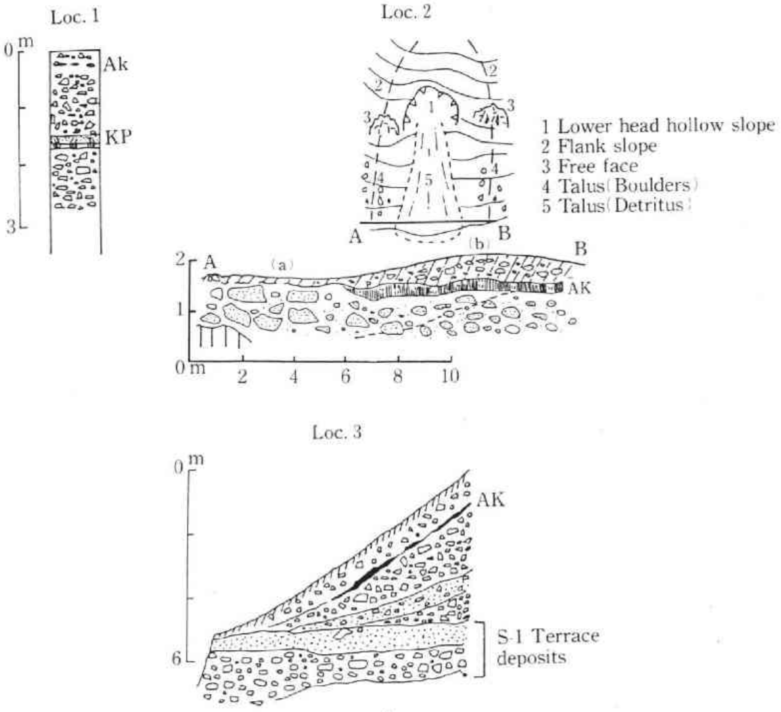


Fig. 11 Exposures of talus and alluvial cones in the Hei River Basin.

layers containing Ak in the upper part form talus in front of the lower head hollow slope. The former layers are considered to have been deposited by rock fall, and the latter are by landslides.

At Loc. 3, talus deposits more than 5.5 m thick are noted on the S-1 terrace deposits along the Oguni River, the branch of the Hei River. Because WL is not observed in S-1 terrace deposits but Ak is found 0.8 m below the talus surface, the talus is considered to have mainly formed between 10 ka and 5 ka.

The talus at Isagozawa (Loc. 4) (Fig. 12), one of the well-developed taluses on the S-1 terrace along the Omoto River, is located in front of a lower head hollow slope. The talus deposits are composed of alternating layers of rubble and buried humic soil which cover Ak (Fig. 13). The C-14 age of one of the buried soil layers is 2,480 yr B. P. (TH-529) (Yoshinaga *et al.*, 1989). The talus deposits were formed by repeated landslides in the posterior slopes (Yoshinaga 1991).

The talus at Loc. 5 was formed in front of steep flank slopes of 40-45° in gradient. The talus was deposited on the interbedded layers of F-3 Terrace and a talus covered with WL including KP. Ak is found between the talus deposits. The talus deposits between Ak and WL are 1.6 times thicker than those above Ak. Considering the ages

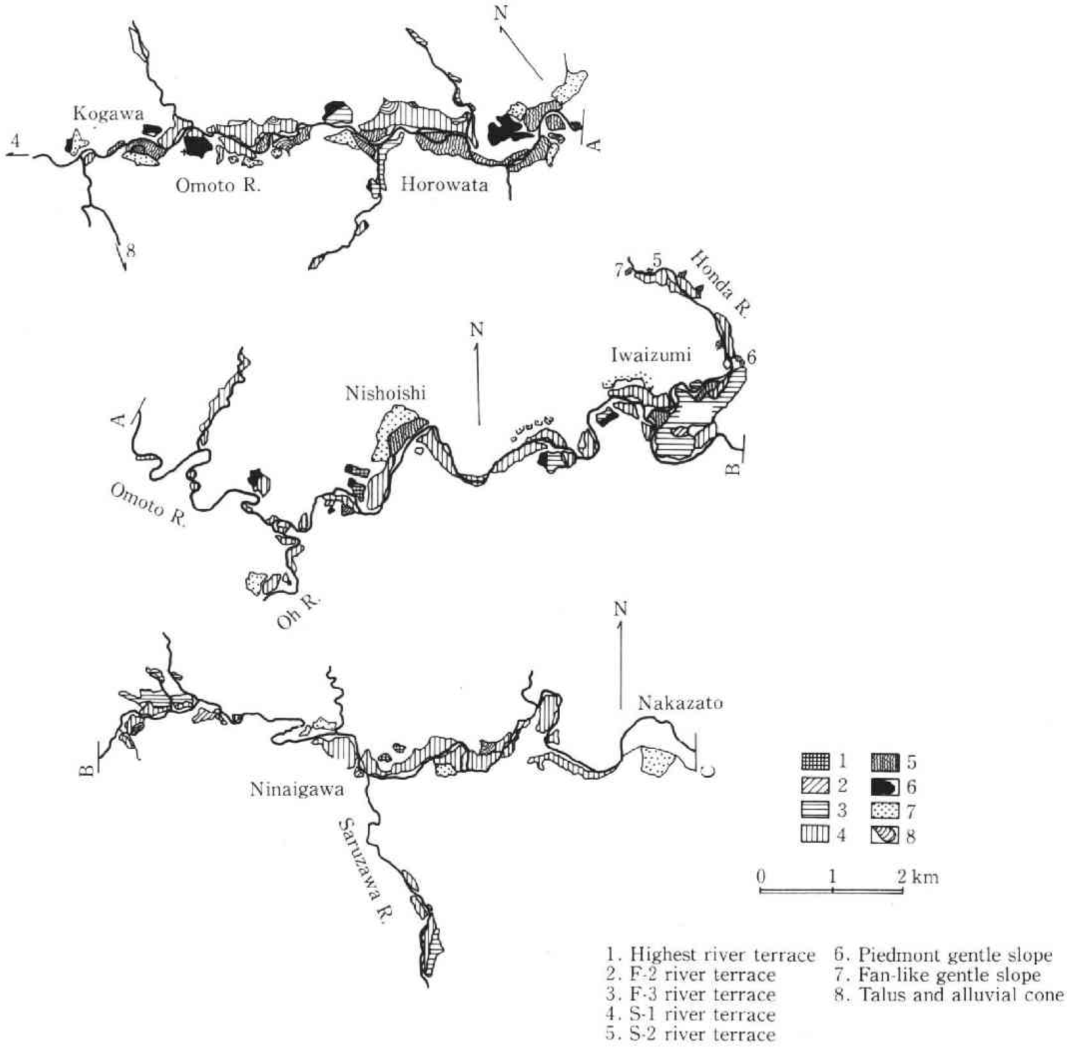


Fig. 12 Morphological map along the Omoto River.

of Ak fall and WL fall, we conclude that the talus deposition in the early Holocene was more active than the time after 5 ka.

A limestone cave called Ryusen-shindo whose entrance had been buried by talus deposits is situated at the foot of the steep valley-side slope along the Shimizu River (at Loc. 6). The deposits burying the cave entrance are, in ascending order, volcanic ash layer with rubble containing HPt, soil layer containing pottery of the beginning of the early *Jomon* Age (layer A), A rubble layer (layer B), Ak, and the other rubble layer (layer C) (Fig. 13 ; Iwaizumi-cho Kyoiku Iinkai 1971).

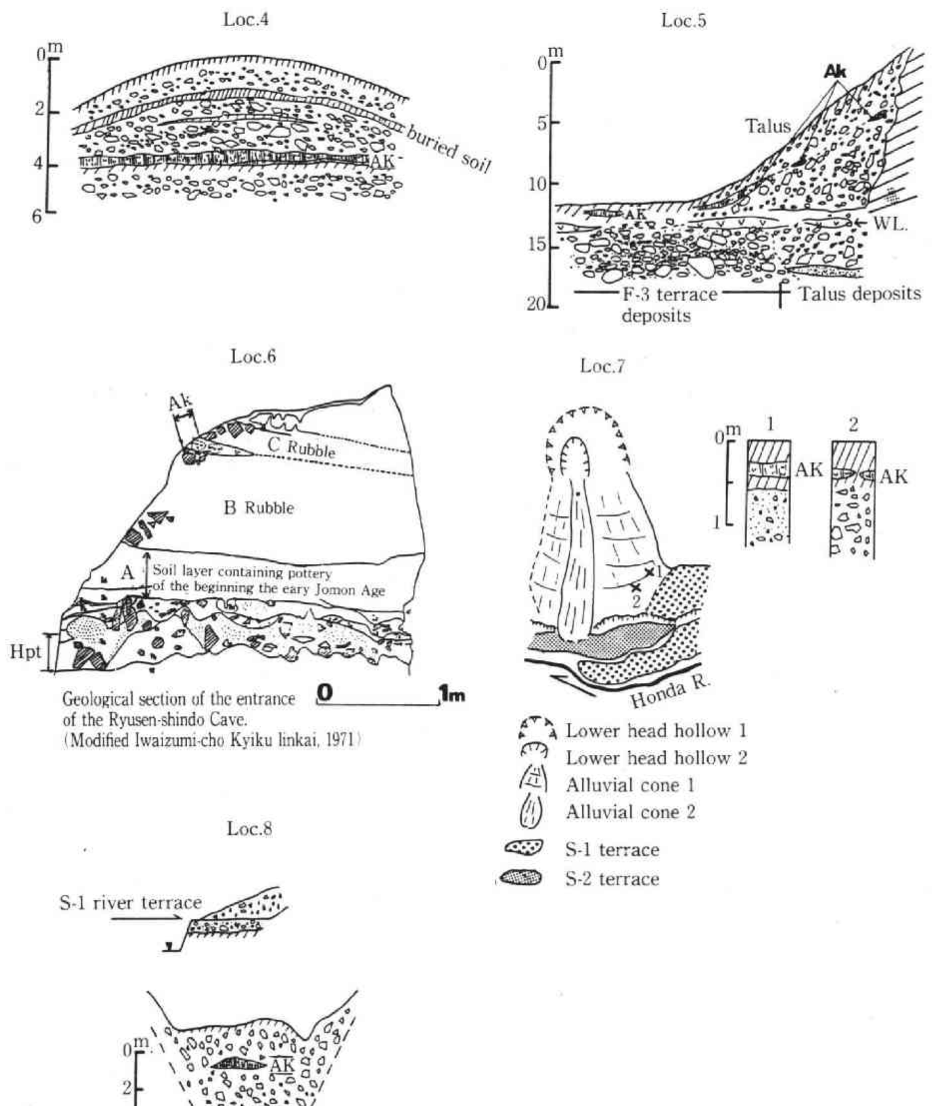


Fig. 13 Exposures of talus and alluvial cones in the Omoto River Basin.

From HPt fall till around the beginning of the Early *Jomon* Age (*i.e.* 10,000 yr B.P.), the entrance of the cave had been fully open, allowing human entry. However, the deposition of talus rubble layers impeded human access after about 10 ka. The main formative period of this talus is between 10,000 and 5,000 yr B.P., because Ak is observed near the surface of the talus rubble layer at the cave entrance. Most alluvial cone deposits intercalate not WL but Ak.

Two alluvial cones of different scales are ones upon another behind S-2 Terraces along the Honda River (Cone 1, Cone 2 at Loc. 7 ; Fig. 13). There is a lower head hollow slope 200 m long and 100 m wide, in which a small lower head hollow slope of 50 m long and 40 m wide exists behind the alluvial cones. Landslides originated in here are thought to have supplied the debris to Cone 1 and Cone 2.

The cone 1 deposits are covered with Ak. Since the base level of the deposition of Cone 1 is lower than S-1 terrace surface, and the foot of Cone 1 is cut by S-2 terrace surfaces, Cone 1 appears to have formed after S-1 terrace surface formation before 5,000 yr B.P.

Ak is not observed in Cone 2,which was formed after 5,000 yr B.P. Considering the difference of the areas and thickness of deposits of Cones 1 and 2, the volume of Cone 1 deposits which formed in the time before 5 ka is seven times greater than that of Cone 2.

The exposure at Loc. 8 reveals a cross section of an alluvial cone which covers the S-1 terrace surface at the mouth of a small valley. Alluvial cone deposits are 7.3 m thick, and Ak is interbedded 2.8 m below the ground surface. Since no clear gullies exist on the alluvial cone, the debris accumulation of this alluvial cone is believed to have been greater in the time between S-1 terrace surface formation and Ak fall than after Ak fall.

In the Hei and Omoto River basins in the eastern Kitakami Mountains, most of talus and alluvial cones were formed after WL fall during the Holocene. The formative processes of talus comprised landslides or rock falls, and those of alluvial cones were landslides or debris flows, as indicated by the existence of lower head hollow slopes or small rivers behind the alluvial cones. Because the volume of talus or alluvial cone deposits provided in the time before Ak fall is larger than that after Ak fall, talus and alluvial cones are considered to have mainly formed between 10 ka and 5 ka in the Holocene. S-1 river terrace surfaces in the eastern Kitakami Mountains were also formed at that time.

5 History of morphogenetic environment with reference to the debris movement system

The history of morphogenetic environment can be learned through morphological development of the total land surface, because the type and intensity of debris movements are affected by climatic conditions. This paper discusses the history of morphpogenetic environment of the central Kitakami Mountains in the late Quaternary, based on the imformation of the formative periods and processes of each landform

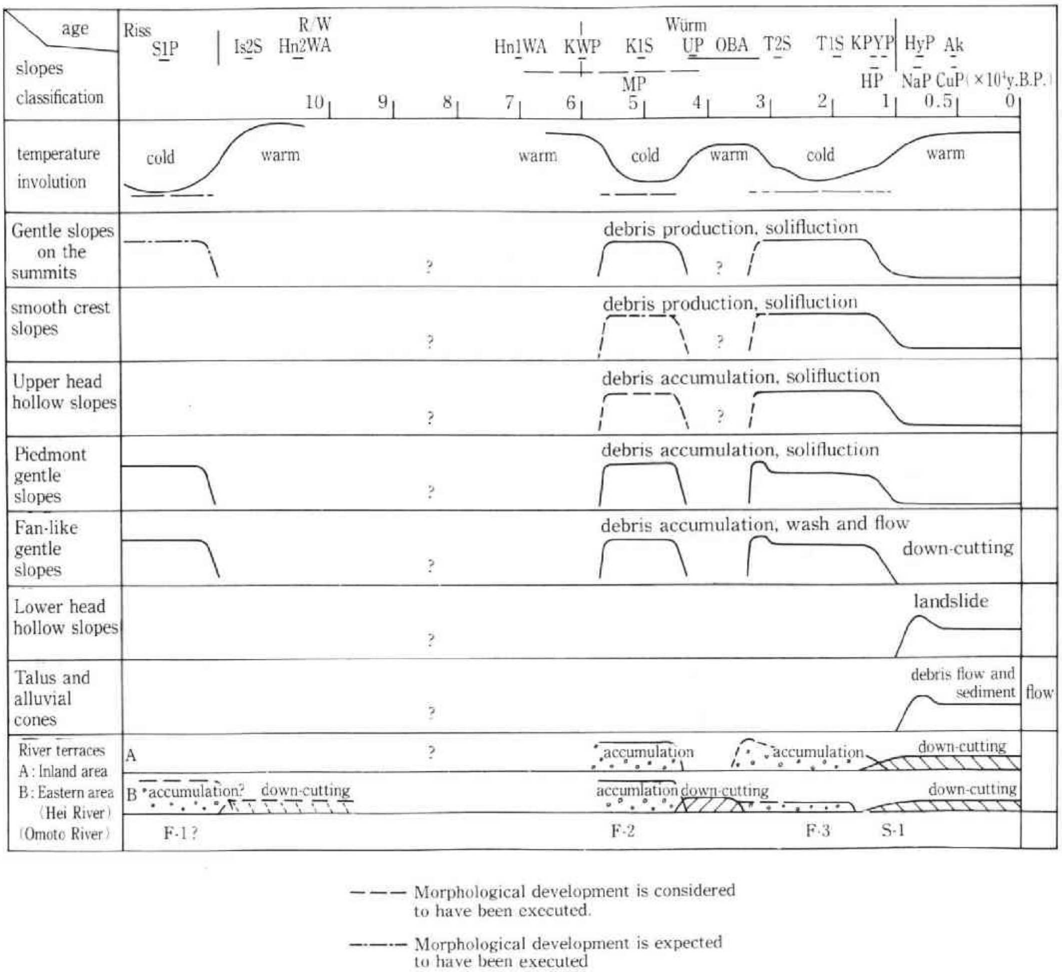


Fig. 14 Morphological development of the Kitakami Mountains.

unit. Therefore, it is necessary to consider previous studies on paleo-vegetation and fossil periglacial phenomena.

Fig. 14 illustrates the history of morphological development in the Kitakami Mountains. Paleo-temperature changes have been presumed on the basis of the ages and the scale of involutions in the volcanic ash sequence of the Kitakami Lowland area (Endo 1977; Inoue *et al.* 1981; Higaki 1987). Previous palynological studies have been also referred to the paleo-climatic changes. Some slope units are supposed or expected to have been formed in a certain stage in consideration of the paleo-climate and the combination of the slopes whose development are confirmed. These slope developments are depicted by the broken lines in Fig. 14.

The next section will discuss the paleo-environmental history of the Kitakami Mountains (also see Fig. 15).

(1) Period before the Last Glacial (Fig. 15-1)

Fig. 15 illustlates the debris movement and land surface development in each stage of morphogenetic paleo-environment.

The Last Interglacial and older periods are presented by the tephera sequence from the upper Sotoyama volcanic ash layer to KWP of the lowermost Shibutami volcanic ash layer. It includes as early cold period indicated by frequent involutions and block streams (Inoue *et al.* 1981) and subsequent warm periods. The early cold period, which precedes the Last Interglacial, probably corresponds to Riss Glacial Age. In the inland area the first formative period of piedmont gentle slopes and fan-like

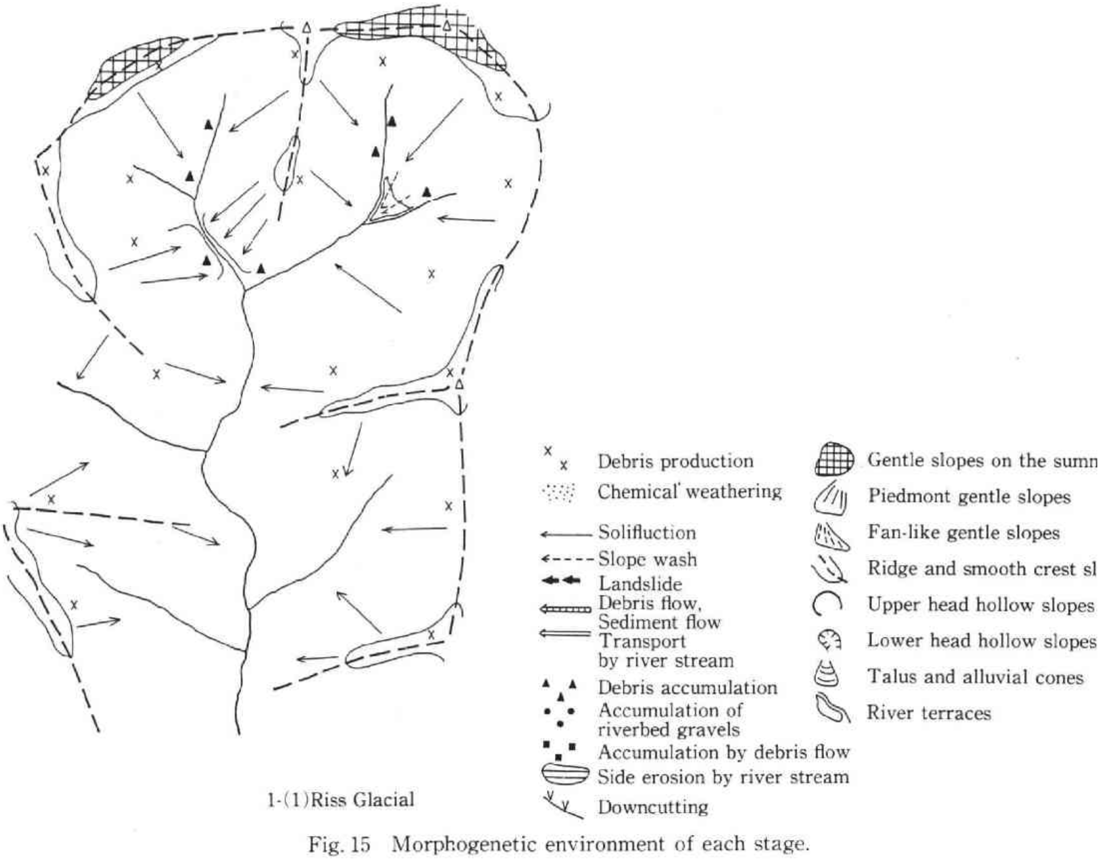
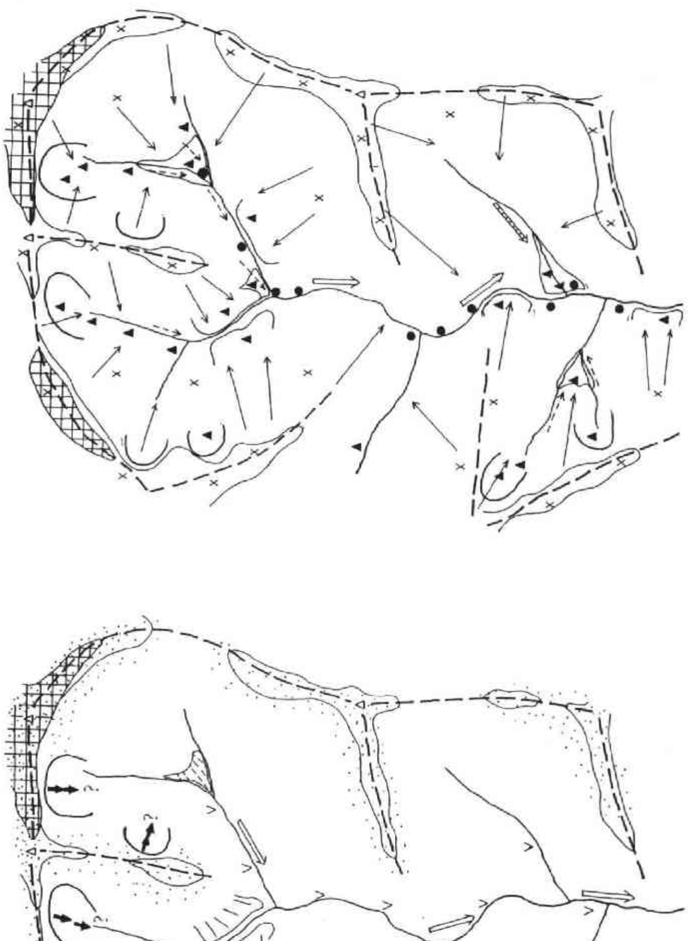
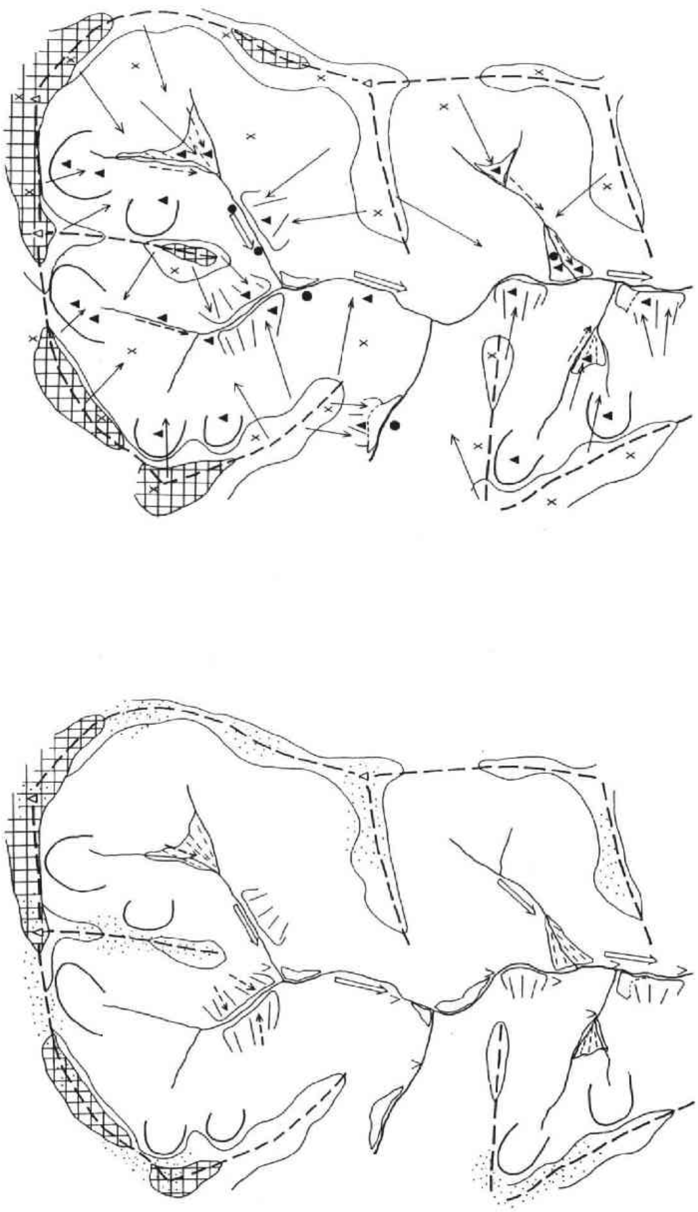


Fig. 15 Morphogenetic environment of each stage.



15-1(2) The Last Interglacial. 15-2 The Early Last Glacial (around 50 ka).

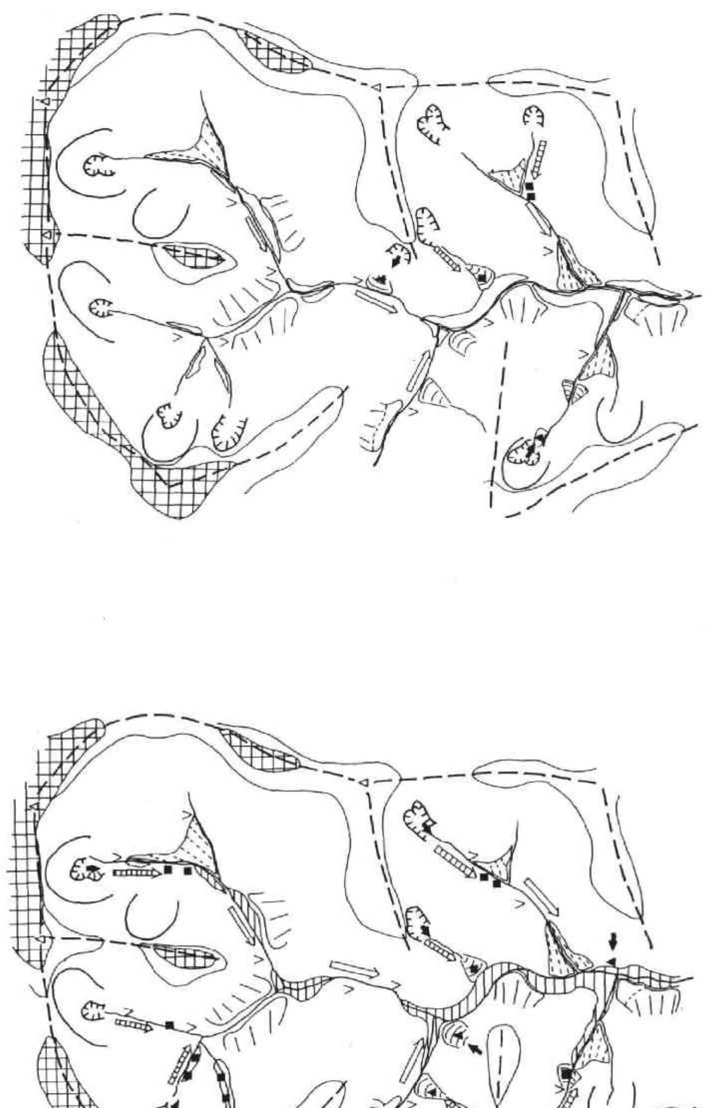
Fig. 15 Morphogenetic environment of each stage (continued).



15-3(1) The Late Last Glacial (around 40 ka).

15-3(2) The Late Last Glacial (around 20 ka).

Fig. 15 Morphogenetic environment of each stage (continued).



15-4(1) The Post Glacial (around 8 ka). 15-4(2) The present.

Fig. 15 Morphogenetic environment of each stage (continued).

gentle slopes are confirmed to be the former cold period. Periglacial climate had dominated, and gentle slopes, as well as smooth crest slopes or summit gentle slopes, might have been formed by debris production and its movement by frost action during the Riss Glacial.

In the eastern area, the F-1 river terrace surfaces were formed simultaneously with the oldest fan-like gentle slopes. In both the inland and eastern areas, the fan-like gentle slopes and the F-1 terraces seem to have been formed under periglacal conditions during the Riss Glacial, although no marker tephras have been observed.

Few slopes formed during the Last Interglacial period have been discovered in the areas surveyed. The bottom deposits of an exposed fan-like gentle slope at Ninai-gawa, Iwaizumi-cho in the eastern area (Higaki 1988), are composed of sediment flow deposits. Because the sediment flow depodits were covered with solifluction deposits of the early Last Glacial, they were probably formed as an alluvial cone in the Last Interglacial. During this period, as in the Holocene slope formation by periglacial processes was not dominated.

Because the deposits of piedmont gentle slopes older than the Last Interglacial are more weathered than those of the Last Glacial, we know that basement rocks of mountain slopes were weathered under warm climatic conditions during the Last Interglacial.

(2) The early Last Glacial (around 50 ka) (Fig. 15-2)

This stage is indicated by the second stage of involutions in the lower Shibutami volcanic ash layer. There is remarkable unconformity between Shibutami volcanic ash layers and the upper Sotoyama volcanic ash layers containing Aso-4 (70 ka) in their uppermost part. OBA is dated 30-40 ka. These chronological evidences suggest that the period of involution formation occurred around 50 ka and did not last longer than 20,000 years.

Palynological data reported in the Yamagata Basin, the central Tohoku region (Hibino *et al.* 1991), show that sub-polar coniferous forests similar to those of the late Last Glacial were dominant in the early Last Glacial. On the other hand, Endo (1977) believes that it was colder in the late Last Glacial than the early Last Glacial, because the vertical thickness of cryoturbated volcanic ash layer, which indicated seasonally active layers, is bigger in the late Last Glacial. The involutions of different layers at Itabashi in the Kitakami Lowland area show that cryoturbated T2S (30 ka) is thicker than K1S (Fig. 16).

These data indicate that the early Last Glacial was not colder than the late Last Glacial. However, debris production and solifluction under periglacial conditions had been dominant in slope formation. Denudation processes, which produced debris from the bed rock, and solifluction created the gentle slopes on the summits and the smooth

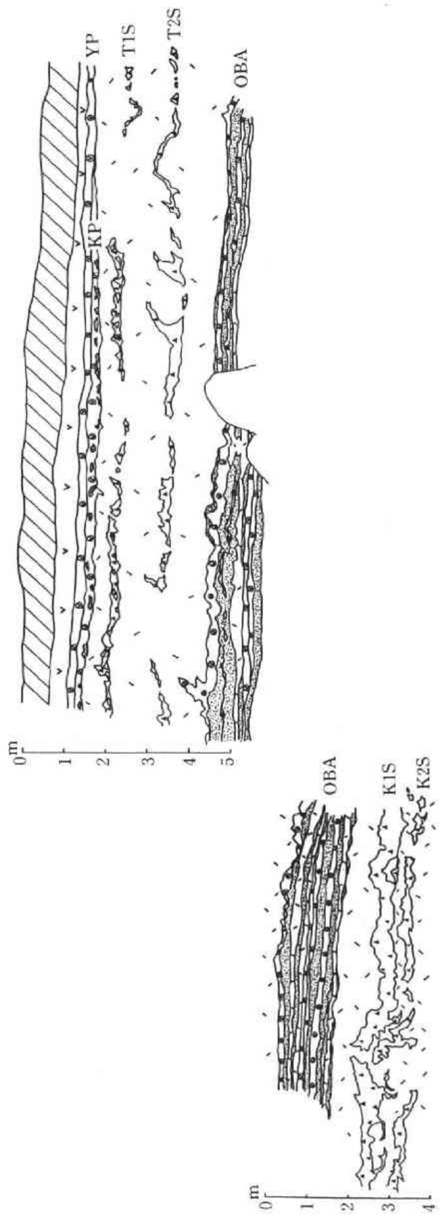


Fig. 16 Involutions of T1S, K2S, K1S and K2S, in the Shibutami Volcanic ash layers in the Kitakami lowland area (Itabashi, Takizawa-mura).

crest slopes. Transported debris was accumulated on the concave slopes such as the valley head hollows or the foot of flank slopes. The upper head hollow slopes and piedmont gentle slopes were thus formed.

Debris transported by solifluction from the summit or flank slopes into the upper river courses was subsequently moved by slope wash and debris flow, and accumulated to form the fan-like gentle slopes at the river joints or valley mouths. In the eastern area, the beds of rivers which have large drainage basins, such as the Hei and Omoto rivers, were risen simultanously with the piedmont gentle slope formation. The F-2 river terrace surfaces have recorded them.

The thickness of the deposits of piedmont gentle slopes or fan-like gentle slopes in this period is bigger than that of the late Last Glacial. Average thickness of the deposits of the early Last Glacial is more than 1.7 m, though the real thickness is larger at some localities because of the base of the deposits has not been observed. The thickness of the deposits of the late Last Glacial is 1.55 m. Because the periglacial conditions in this period lasted 20,000 years, which is almost the same as the late Last Glacial from 30 ka to a few thousand years before 10 ka, debris movement is considered to have been more active during this period than the latter period.

(3) The late Last Glacial (40 ka to 10 ka) (Fig. 15-3)

This period is divided into the former warm period and the latter cold period. The boundary is distinguished around a few thousand years before 30 ka (Higaki 1987).

Involutions are observed in the uppermost layers of OBA which fell around 30 ka. Palynological data suggest a warm period around 40 ka (Yasuda 1987 ; Nakayama and Miyagi 1984). Slopes became unstable around a few thousand years before 30 ka because of the coldward climatic changes (Higaki 1987).

The gravel of slope deposits interbeded in the upper OBA is more weathered than that of the early Last Glacial. Therefore, a warm period suitable for chemical weathering is considered to have existed before the coldward climatic change. The movement of debris·produced under cold climate after a few thousand years befor 30 ka is thought to have been more dominant than the removal of the deposits produced in the cold climate of the early Last Glacial.

The beds of larger rivers in the eastern Kitakami Mountains are believed to have been entrenched, and the F-2 fill top surfaces were terraced in or before 40 ka, because the deposition of the F-3 terraces began in the time near upper OBA fall in the eastern prot of the Omoto River basin.

Palynological studies (Sakaguchi 1978 ; Yasuda 1987) indicated that the cold period was dominant around 20 ka. Judging from the vertical thickness of cryoturbated layers, the coldest period in the Kitakami Mountains was around or before 20 ka. Inoue *et al.* (1981) estimated that the temperature in this period was 8℃ below that of

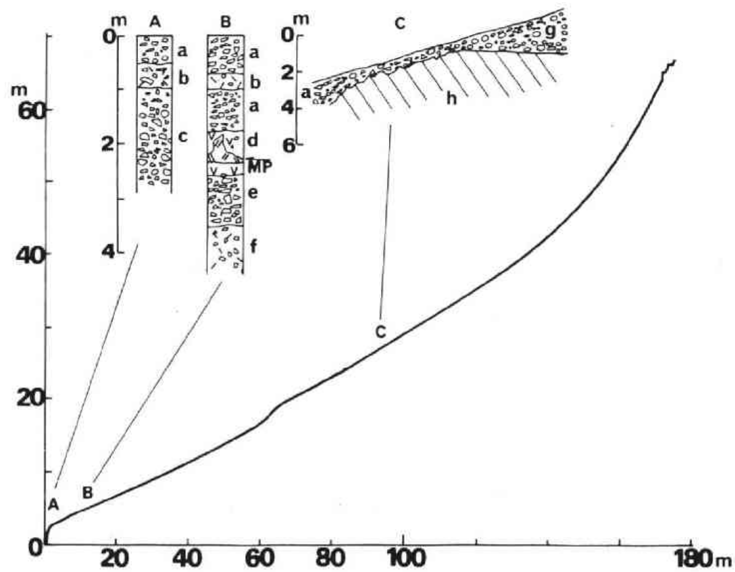


Fig. 17 Cross section of the piedmont gentle slope at Tsunagi. (Higaki 1988)
a ; rubble layer, b ; rubble layer with clayey volcanic ash matrix, c ; fluvial gravels of the F-2 terrace mixed with rubble, d ; pumicious loamy ash, e ; rubble layer, f ; rubble layer with clay matrix, g ; fluvial gravels layer of the terrace higher than the F-2 terrace, h ; bed rock.

the present by comparing the vertical thickness of involutions and the present earth hummocks on the summit of Mt. Akitakomagatake (1,637 m). Inland areas above 600 m a.s.l. whose mean annual temperature is presently 6-7℃ might have had mean annual temperature below 0℃. Bed rocks and debris slopes were exposed on the slope surfaces, as indicated by the deposits and bedrocks which were directly covered with KP on gentle slopes on the summits.

The continuous longitudinal exposure of the summit gentle slopes shows that the undulating bed rock surface had been buried by the rubble deposits of the cold period (Higaki 1987 ; Fig. 5a). In that time, as in the early Last Glacial, debris production and solifluction were dominant morphological processes on the summit and crest slopes, forming the gentle slopes on the summits and the smooth crest slopes. On the foot slopes, debris created by solifluction were accumulated and partly denudated the projecting part. The exposure of the piedmont gentle slope at Tsunagi along the Oguni River (Fig. 10) shows a denudated feature at the shoulder of an old river terrace (point C) and debris accumulation on the terrace surface without any change in slope gradient (Fig. 17). After the formation of river terrace at point C, debris was deposited on the terrace surface and projecting parts of terrace shoulder were denudated in the time of piedmont gentle slope formation. These facts indicate that mountain slopes became more gently undulated through surficial denudation and accumulation during this period.

The fan-like gentle slopes developed in the same manner as in the early Last Glacial. However, the formation of the fan-like gentle slopes must have been caused partly by solifluction, because some of the fan-like gentle slopes were composed of solifluction deposits derived from the side slopes.

Fill top terraces formed during this period (the F-3 terraces) are distributed only in small drainage basins. The gravel size of the fan-like gentle slopes is smaller than that of the present river beds (Higaki 1987). Since solifluction deposits of the fan-like gentle slopes have not been confirmed in the deposits of the early Last Glacial, there must have been less precipitation at that time than in the present, and river water discharge was probably not enough to transport debris from the upper river basin. The F-3 terraces are not believed to have formed along large rivers such as the Hei and the Omoto in the eastern part.

In the Kuzakai Highlands 700 m a.s.l., fossil spore of *Selaginella selaginoides* in the peat layer and the distribution of the peat layer on the piedmpost gentle slopes indicate the paleo-vegetation of this area in the comparisom with the present microenvironment of *Selaginella Selaginoides* (Miura *et al*. 1992). The foot of the piedmont gentle slope was probably like a snow patch grassland, and debris was sometimes transported on the grassland from the upper part of the slope.

The active and surfacial mass movement by solifluction began to decline a few thousand years before 10 ka, and the area of active mass movement retreated to the high elevations and steep slopes (Higaki 1987).

(4) Post-Glacial Period (after 10 ka) (Fig. 15-4)

After the Last Glacial, dominant processes of slope formation changed from slow and widespread mass movement such as solifluction or slope wash to rapid ones such as landslides, debris flow and sediment flow (Higaki 1987). Landslides formed the lower head hollow slopes at the valley heads where debris had already accumulated during the Last Glacial. Debris produced at the lower head hollow slopes was transported to the foot slopes, and accumulated as the talus and the alluvial cones. Valleys of first order streams were formed after landslides, as Miyagi (1978) pointed out in the hilly area around Sendai. These rapid mass movements were more active in the time from 10 ka to 5 ka than after 5 ka.

Nakayama and Miyagi (1984) indicated that debris production on mountain slopes had been active in the time between 11 ka and 8.7 ka in the central Tohoku region. Yasuda (1982) also noted that slopes had been unstable in the warming period after 13-12 ka when humidity increased. These palynological and stratigraphical studies support the period of slope instability during the time from the late Last Glacial to the early Holocene. Thus frequent debris production by landslides in the early Holocene is attributed to warmward and humidward climatic changes.

The S-1 river terraces have wide erosional surfaces, which were probably formed by landslides and rock falls on side slopes of rivers and by transportation of debris by large river discharge. Such rapid mass movements became less active after 5 ka, and the river bed was cut down and the S-1 river terrace was formed.

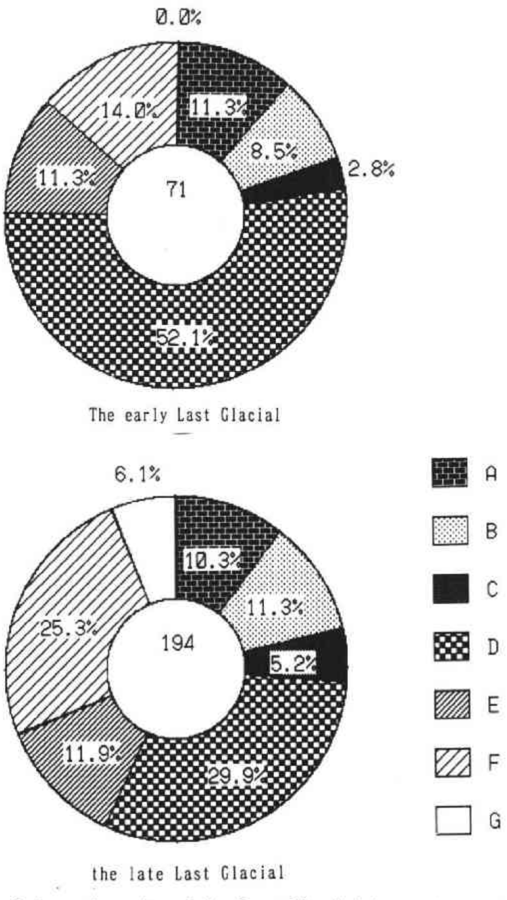


Fig. 18 Materials of slope deposits of the Last Glacial Age. (except talus and alluvial cone. The number at the center of each graph means total number of exposures observed).
A : volcanic ash, B : volcanic ash with rubble, C : rubble with volcanic ash matrix, D : rubble with clay matrix, E : sandy gravel, F : rubble with little matrix, G : clay or sand

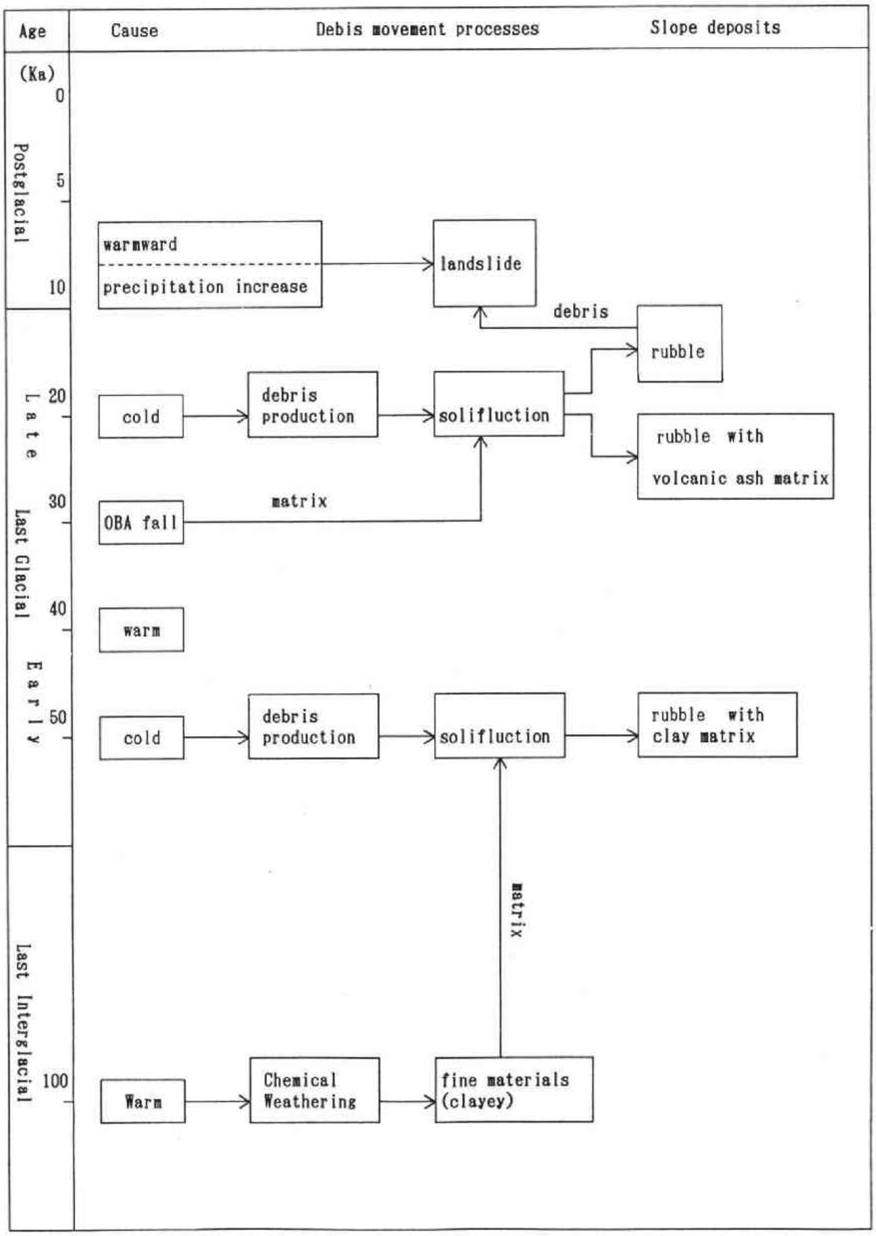


Fig. 19 Relationship between the paleo-environmental stages in morphological development.

6 Relationships among the stages of morphologenetic environment

Matsumoto (1971) pointed out that core stones and fine materials created by chemical weathering during the Last Interglacial had formed block streams by solifluction during the Last Glacial. Thus, the morphogenetic processes of one paleo-environmental stage play an important part in the subsequently morphological development of the next stage.

The materials of slope deposits of the early Last Glacial are mainly (Fig. 18) composed of rubble with clay matrix originated in bed rock rather than volcanic ash, but those of the late Last Glacial are composed of rubble with little matrix or with volcanic ash (Fig. 18). Clayey matrix of the former period was produced by chemical weathering of bed rocks during or before the Last Interglacial. However, the Sub-stage of Interglacial during the Last Glacial was neither warm enough nor long enough to weather bed rocks and to supply clayey matrix in the late Last Glacial. OBA fall, which was widely deposited in the central Kitakami Mountains, probably supplied matrix for solifluction in the late Last Glacial. The fact that slope formation by solifluction was more active in the early Last Glacial than in the late Last Glacial is attributed not only to precipitation but also to matrix supplied sufficiently from weathered bedrock for solifluction.

Because the lower head hollow slopes are often located in the upper head hollow slopes, landslides during the Holocene is considered to have mainly originated from the debris which had been deposited by solifluction during the Last Glacial. Not only humidward climatic change but the preparedness of debris in the Last Glacial caused frequent landslide occurence in the early Holocene. The relationships between each stage are shown in Fig. 19.

7 Conclusion

Total landsurface development, including mountain slopes and river landforms, was examined by investigating changes of debris movement system in the central Kitakami Mountains. The history of morphogenetic environment could be learned through the changes of deblis movement system.

Eight slope units, three fill top terraces (F-1, 2, 3), and well-continous strath terraces (S-1) along rivers are recognized in the study area. There were two types of slopes which originated during the Glacial Period and Interglacial or Post-glacial Period.

Three stages of involutions have been noted in the Quaternary volcanic ash layers. The first one dates before the Last Interglacial. In this period piedmont gentle slopes and fan-like gentle solpes were formed by solifluction. The second stage occurred during the early and the late Last Glacial (around 50 ka and a few thousand before 30 ka to 10 ka, respectively). In these stages, debris production and solifluction were widely dominant on the summit and crest slopes, forming the gentle slopes on the summits and the smooth crest slopes as denudational slopes. Debris transported by solifluction was accumulated at the vally head hollows and foot parts of slopes, and formed the upper head hollow slopes and the piedmont gentle slopes which were mainly of depositional and partly of denudatial origin. In upstream areas debris from the side slopes was transported by slope wash or debris flow, and formed the fan-like gentle slopes in the early Last Glacial. During the late Last Glacial, solifluction played an important role in the formation of the fan-like gentle slopes. River bed aggradation corresponding to slope formation occurred in the early and late Last Glacial, and the F-2 and F-3 terrace surfaces were formed.

During the Holocene, rapid mass movements such as landslide and debris flow became dominant processes, and the lower head holow slopes were formed in the upper head hollow slopes or flank slopes. Debris provided from the lower head hollow slopes was transported by debris flows to form the talus and the alluvial cones. These processes were more active in the early Holocene (10 ka-5 ka) than after 5 ka. The S-1 terraces with wide surfaces were formed in the early Holocene. This might be explained by increases in river water discharge and valley side erosion caused by landslides.

The relationships between each stage of the change of morphogenetic environment were pointed out based on the debris movement and total landsurface development associated with climatic change. Mass movements were more active during the early Last Glacial than in the late Last Glacial, because chemical weathering in the Last Interglacial had supplyed greater clayey matrix for solifluction in the former period. Landslides in the early Holocene were mainly conditioned by the debris which had been accumulated during the Last Glacial.

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