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Karst Geomorphology

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FOSSIL PERIGLACIAL PHENOMENA ON KARST IN THE LATE QUATERNARY IN THE AKKA KARST, NORTHEASTERN JAPAN

ABSTRACT: OKAMOTO T., *Fossil Periglacial Phenomena on Karst in the late Quaternary in the Akka Karst, Northeastern Japan*. (IT ISSN 0391-9838, 1998).

Fossil periglacial phenomena on karst in the late Quaternary in the Akka Karst, northeastern Japan, were investigated tephrochronologically. The limestone bedrock in the study area is overlain by several late Quaternary tephtras. The tephtra overlying a slope on karst indicates that the slope has been stabilized since the tephtra fell. On the other hand, the absence of a tephtra layer, which is usually found at the bottom of dolines or at the foot of slopes, implies slope instability after the falling of the tephtra. On the karstic plateau, there are some fossil periglacial deposits which were presumably formed around 50 ka BP and during 30 to 10 ka BP. Pleistocene tephtras are absent on the gentle slopes as well as on the steep slopes, whereas Holocene tephtras are present on the gentle slopes. Therefore, Pleistocene tephtras on the slopes in the Akka Karst were mainly removed by periglacial processes, such as solifluction and frost shattering of limestone bedrock, in the cold phases of the Last Glacial Stage. The periods of slope evolution by periglacial processes are considered to be around 50 ka BP and from 30 to 10 ka BP, which are in accord with those of mass movement in the Central Kitakami Mountains, and of involution and solifluction lobes in the Northern Kitakami Lowland. The high content of biotite, which derived from granitic rocks, in soils in the bottom of dolines indicates that bare ground affected by periglacial processes was distributed over the summits of granitic mountains adjacent to the Akka Limestone during the late Pleistocene. Accordingly, allogenic deposits on karst in the study area have helped to reconstruct environmental conditions in non-limestone areas as well as in limestone areas.

KEY WORDS: Preiglacial, Karst, Tephtra, Japan.

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INTRODUCTION

The karstic areas in Japan are mostly covered with eolian deposits, notably tephtras and long-range eolian dust transported from inland China (Machida & alii, 1985; Mizota & Matsuhisa, 1985; Okamoto, 1995). These deposits are used not only as important time-markers but also as evidence of environmental changes. Valuable information can be obtained from the surface environment in limestone areas because superficial deposits have been well preserved in closed depressions (dolines) that have developed on karst. According to Bull (1980) and Gunn (1986), most sediments in caves have also remained essentially unaltered since the initial deposition. In Japan, moreover, it is relatively easy to distinguish between the residuum of limestone and allogenic deposits, because most of the limestone in Japan consist of very pure calcium carbonate which originated from coral reefs. However, there are few studies about superficial deposits on karst in northern Japan. The purpose of this paper is to clarify fossil periglacial phenomena on karst in the late Quaternary in the Akka Karst, northeastern Japan. The limestone bedrock in the Akka Karst is overlain by several late Quaternary tephtras, which make it possible to investigate fossil periglacial phenomena and slope evolution tephrochronologically.

OUTLINE OF THE AKKA KARST

The Akka Limestone is distributed in the northeastern part of the Kitakami Mountains, northeastern Japan (fig. 1). The Omoto River, Akka River, and Osanai River flow eastward from a non-limestone area in the Kitakami Mountains and dissect the Akka Limestone into blocks of

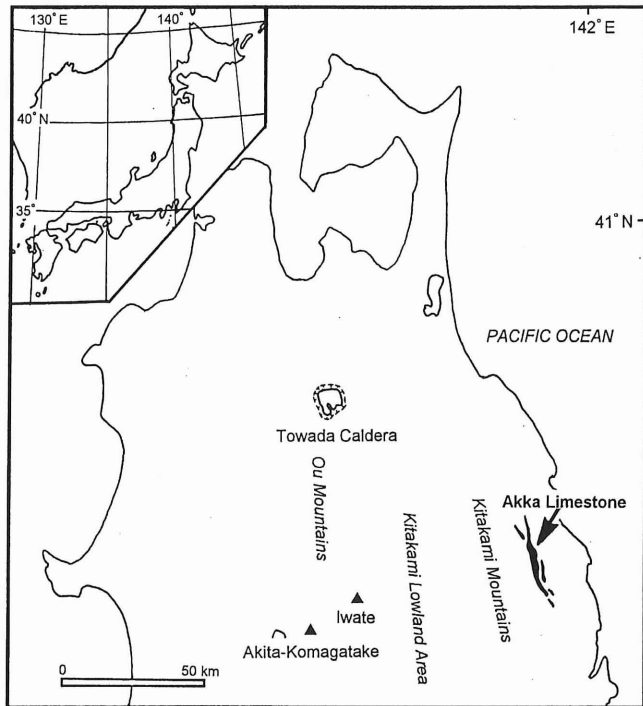


FIG. 1 - Location map in the study area, showing the occurrence of the Akka Limestone.

karstic plateau up to 400-700 m above sea-level (fig. 2). More than 100 caves have been recognized in the Akka Limestone. Dolines are well developed, especially in the northern part of the study area.

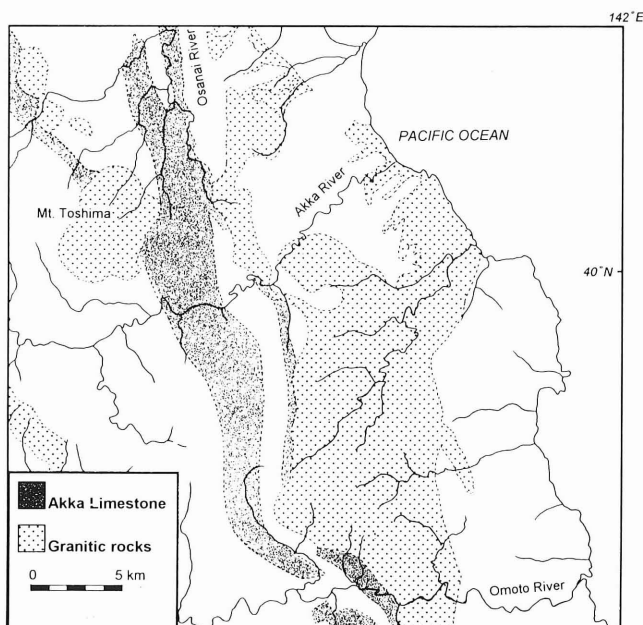


FIG. 2 - Geological map of the study area.

The geology of the Akka Karst has been discussed by Sugimoto (1974), Murai & *alii* (1985), Okami & Ehiro (1988), and Okami (1992). The Akka Limestone, which is 50 km wide in the N-S direction, 1-4 km wide along the E-W direction and has NNW-SSE strike (fig. 2), is a member of the Akka Formation (700 m in thickness) which consists of bedded limestone, alternating beds of limestone and chert, and comprises chert in an upward sequence. The Akka Formation is considered to have formed on seamounts in the late Triassic. The limestone bedrock is overlain by several late Quaternary tephras as stated later in detail.

Fig. 3 shows that the climate in the Akka Karst is characterized by warm humid summers and cold wet winters. The mean annual precipitation and temperature are 1,131 mm and 9.9 °C. Precipitation is evenly distributed throughout the year with much rain from July to September. Snow often falls during December to March.

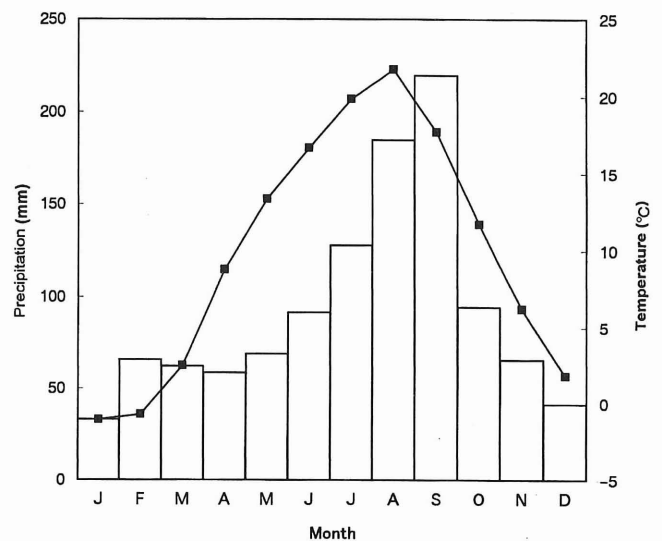


FIG. 3 - Mean monthly temperature and precipitation statistics in the study area (1986-1996). Mean annual temperature is 9.9 °C. Mean annual precipitation is 1131 mm.

Several thousands of years ago, before human activities changed the landscape, a beech (*Fagus crenata*) forest presumably occupied most parts of the study area. Now the vegetation has mostly changed to secondary forests, planted forests and pastures. The larger part in the study area is now occupied by secondary communities dominated by deciduous oak (*Quercus mongolica* var. *grosseserrata*) or birch (*Betula ermanii*), and by plantations of Japanese larch (*Larix karmpperi*), Japanese cedar (*Cryptomeria japonica*) and Japanese red pine (*Pinus densiflora*). Pastures are distributed on the karstic plateau in the northern part of the study area.

METHODS

In order to clarify fossil periglacial phenomena and the changes of slope stability on the karst, a tephrochronological study was carried out at many exposures and pits in the Akka Karst. Tephra overlying a slope indicates that the slope has been stabilized since the tephra fell. On the other hand, the absence of a tephra layer, which is usually found at the bottom of dolines or at the foot of slopes, implies slope instability after the falling of the tephra.

For the tephra investigations, the first steps were to determine the stratigraphic position and lithofacies at each site. Secondly, petrographic properties such as mineral composition and shape of volcanic glass of each tephra were described by microscopic observation. Finally, refractive indices of volcanic glass shards and orthopyroxene were measured. Identification of tephras was based on a combination of these features and comparison with data in a catalog for Japanese tephras (Machida & Arai, 1992).

RESULTS

Identified tephras in the Akka Karst

Table 1 shows the results of the analyses of the tephras. Schematic columnar section of identified tephras in the study area and columnar sections at some exposures and pits are shown in fig. 4. The distribution of tephras around the Akka Karst has been discussed by Higaki (1988), Saijo & alii (1993), and Yoshinaga & Koiwa (1996). The eruption ages of tephras have been reported by previous studies (Oike, 1972; Hayakawa, 1983; Doi & Oishi, 1992; Machida & Okumura, 1996; Wachi & alii, 1997). The marker tephras in the study area have been identified as follows:

TABLE 1 - The identified marker tephras in the Akka Karst

Tephra	Source volcano	Age (ka)	Mineral composition	volcanic glass Type	volcanic glass n	opx γ
To-a	Towada	915 AD	opx, cpx	pm	1.493-1.503	
To-Cu	Towada	5.5	opx, cpx	pm	1.511-1.515	
To-Nb	Towada	8.6	opx, cpx	pm	1.510-1.521	
Ak-Y	Akitakoma	11.6-11.9	opx, cpx			
To-H	Towada	12.6	opx, cpx, ho	pm	1.500-1.510	
Iw-Od	Iwate	35-40	opx, cpx	pm		1.721-1.727
Toya	Toya	103-123	vitric	pm>bw	1.493-1.498	

opx, orthopyroxene; cpx, clinopyroxene; ho, hornblende, pm, pumiceous glass shard; bw, bubble-walled shards. eruption age by Machida & Arai (1992), Machida & Okumura (1996), Wachi & alii, (1997).

To-a (Towada-a: 915 AD), To-Cu (Towada-Chuseri: 5.5 ka BP), To-Nb (Towada-Nanbu: 8.6 ka BP), Ak-Y (Akita-Komagatake-Yanagisawa: 11.6-11.9 ka BP), To-H (Towada-Hachinohe: 12.6 ka BP), Iw-Od (Iwate-Oide: 35-40 ka BP), Toya (Toya: 103-123 ka BP).

To-a, To-Cu, To-Nb and To-H originated from eruptions from the Towada caldera. To-H is recognized as a pyroclastic flow deposit in the study area. Ak-Y and Iw-Od originated from eruptions of Akita-Komagatake and Iwate volcanoes, respectively, on the Ou Mountains (fig. 1). Toya is a widespread tephra which erupted from Toya caldera, Hokkaido Island, and provides a useful time-marker in northern Japan. This tephra presumably erupted before the oxygen isotope stage 5e, because it mantles the marine terraces assigned to the Last Interglacial Maximum (isotope stage 5e) in northern Japan (Miyuchi, 1988).

Description of the deposits on karst

Pleistocene tephras are observed on the karstic plateau. At an exposure on the plateau, loamy soils including Toya and the unconformity below Toya are found (fig. 5). This indicates that the unconformity existed before the falling of Toya and should have formed before the Last Glacial

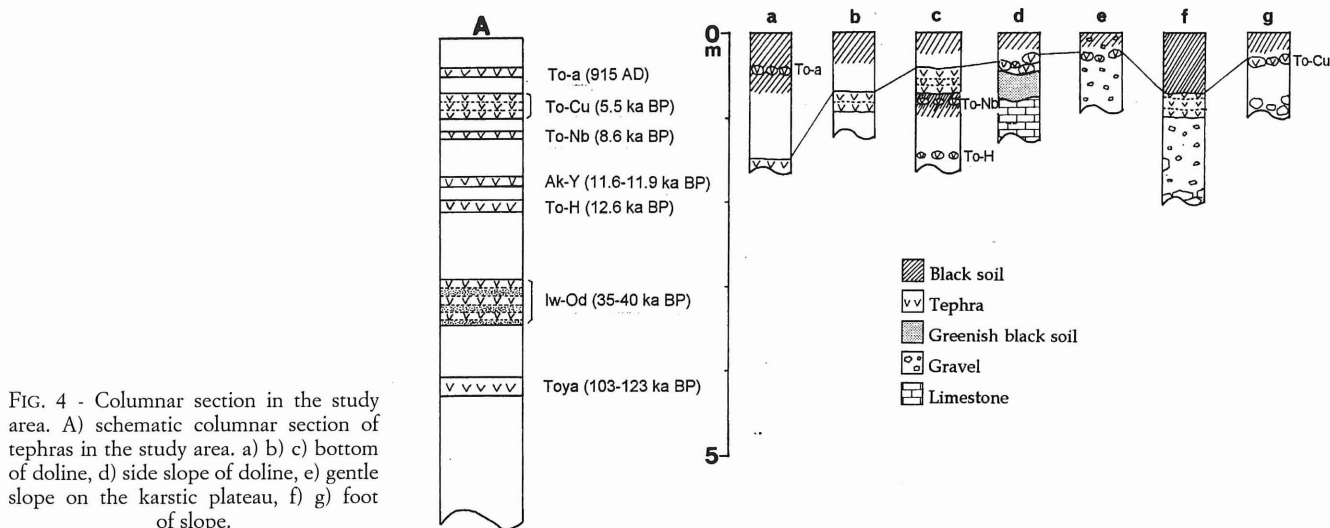


FIG. 4 - Columnar section in the study area. A) schematic columnar section of tephras in the study area. a) b) c) bottom of doline, d) side slope of doline, e) gentle slope on the karstic plateau, f) g) foot of slope.

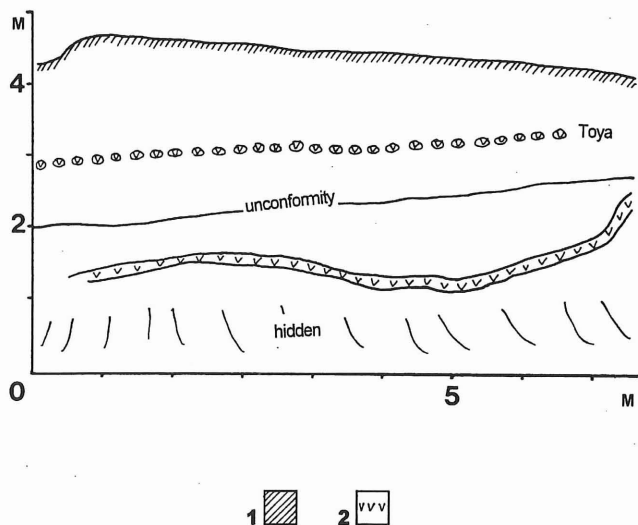


FIG. 5 - Sketch of the exposure on the karstic plateau. 1) humus layer, 2) tephra.

Stage by the eruption age of Toya (103-123 ka BP). Another tephra is observed below the unconformity, but it is still unidentified.

Fig. 6 shows that a buried breccia layer is directly overlaid by Iw-Od. The breccia layer mainly consisted of chert, about 30-100 cm in thickness with a loamy matrix that was derived from tephras. In addition this layer has terrace-like forms, with its angular materials oriented highly parallel to

the former slope direction (10-20 degrees). The drag structures toward down slopes are present in the greenish black soils which originated from limestone bedrock (fig. 6). These facts indicate that the buried breccia layer was formed by periglacial processes. A thin humus layer also developed in the uppermost part of this layer. Therefore, formation of the breccia layer was completed before Iw-Od fell. Iw-Od is covered with secondary deposits and unstratified slope deposits with a fine matrix. The slope deposits are mainly composed of tephras and include unsorted limestone and chert pebbles. These deposits are also thought to have been formed by periglacial processes. Other tephras and reddish clay soils are found under the breccia layer.

To-H is recognized at the bottom of dolines (fig. 4c) and at the head hollows on the karstic plateau. In the northern part of the study area, soils under To-H in the bottom of the dolines have many biotites which neither the Akka Limestone nor tephras identified in the study area contain.

Holocene tephras, To-a, To-Cu and To-Nb, have remained at the surface in the nearly flat bottom of dolines (fig. 4 a, b and c). In particular, To-Cu is well preserved with a thickness of 30 cm, and essentially three air-fall units can be discriminated (fig. 4 c). To-Cu is observed as a layer at the foot of the slopes (fig. 4f and g) and as patches on the gentle slopes such as side slopes of closed depressions (fig. 4d and e). At some exposures on the gentle slopes, greenish black soil that originated from limestone is partly covered with To-Cu (fig. 4d). On the steep slopes, no tephra layers are observed, and limestone bedrock is exposed at several places.

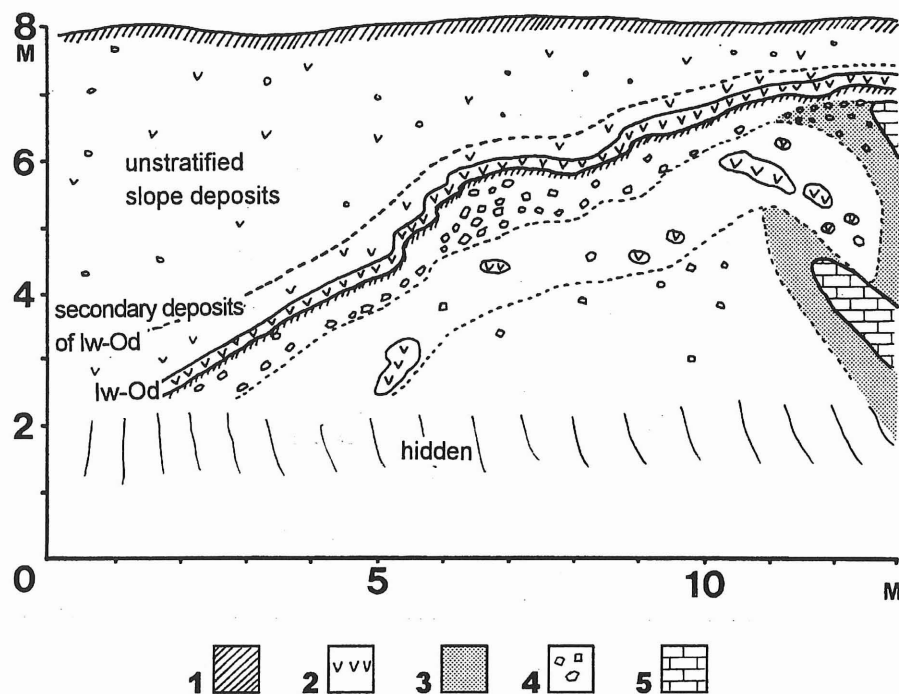


FIG. 6 - Sketch of the periglacial deposits on the karstic plateau. 1) humus layer, 2) tephra, 3) greenish black soil, 4) gravel, 5) limestone.

DISCUSSION

In the Central Kitakami Mountains, two periods of mass movement by periglacial processes have been confirmed to have occurred during the Last Glacial Stage (Higaki, 1987). The first period was in the early Last Glacial Stage, around 50 ka BP, and the second was in the late Last Glacial Stage, between 30 and 10 ka BP (fig. 7). At these times, involution and solifluction lobes were formed in the Northern Kitakami Lowland about 200-300 m above sea-level (Okami & Doi, 1978; Inoue & *alii*, 1981; Sawaguchi, 1992), as shown in fig. 7.

The unconformity at an exposure on the edge of the karstic plateau (fig. 5) was formed before the Last Glacial Stage due to the stratigraphic position of Toya (103-123 ka BP), although it is difficult to identify its formation process. The age and environmental conditions of the unconformity would be clarified by identification of a tephra below it.

Fig. 6 shows that the breccia layer at an exposure on the edge of the karstic plateau was formed by periglacial processes before the Iw-Od fall (35-40 ka BP). Although it is necessary to investigate the deposits in more detail, the vegetation was probably poor while the breccia layer was forming. The humus layer in the uppermost part of the breccia layer implies that periglacial processes had been weakened before the Iw-Od fall. These facts show that the formation age of this layer is in accord with first period of mass movement in the Central Kitakami Mountains around 50 ka BP under periglacial conditions. Iw-Od was covered with secondary deposits and unstratified slope de-

posits with a fine matrix, which is mainly composed of tephras. Thus, these deposits formed for a while after the falling of Iw-Od, about 30 ka BP. Similar slope deposits including To-H in their uppermost part are often found in the head hollows on the karstic plateau. According to Higaki (1987), debris accumulation occurred on the upper head hollow in the Kitakami Mountains during the late Last Glacial Stage. Therefore, the formation period of the unstratified slope deposits probably agrees with the second period of mass movement in the Kitakami Mountains between 30 and 10 ka BP under a periglacial climate.

Pleistocene tephras are absent both on the steep slopes and on the gentle slopes. At some exposures on the gentle slopes, it is often observed that greenish black soil derived from limestone bedrock is directly covered with To-Cu that erupted 5.5 ka BP (fig. 4 d). These observations imply that Pleistocene tephras on the slopes had already been denuded before the Holocene, i.e., before the falling of To-Cu. On the steep slopes, frost shattering of underlying bedrock was probably extensive, because the bedding plane and joint are well developed in the Akka Limestone. Consequently, most of the Pleistocene tephras on the slopes in the Akka Karst were removed by periglacial processes in the cold phases of the Last Glacial Stage. During the periglacial period, some karst depressions were presumably filled in with soliflucted debris. There are some dolines which have collapsed rims at the margin of the limestone plateau in the study area. These might be caused by periglacial processes.

In the northern part of the study area, soils under To-H (12.6 ka BP) in the bottom of the dolines show a high

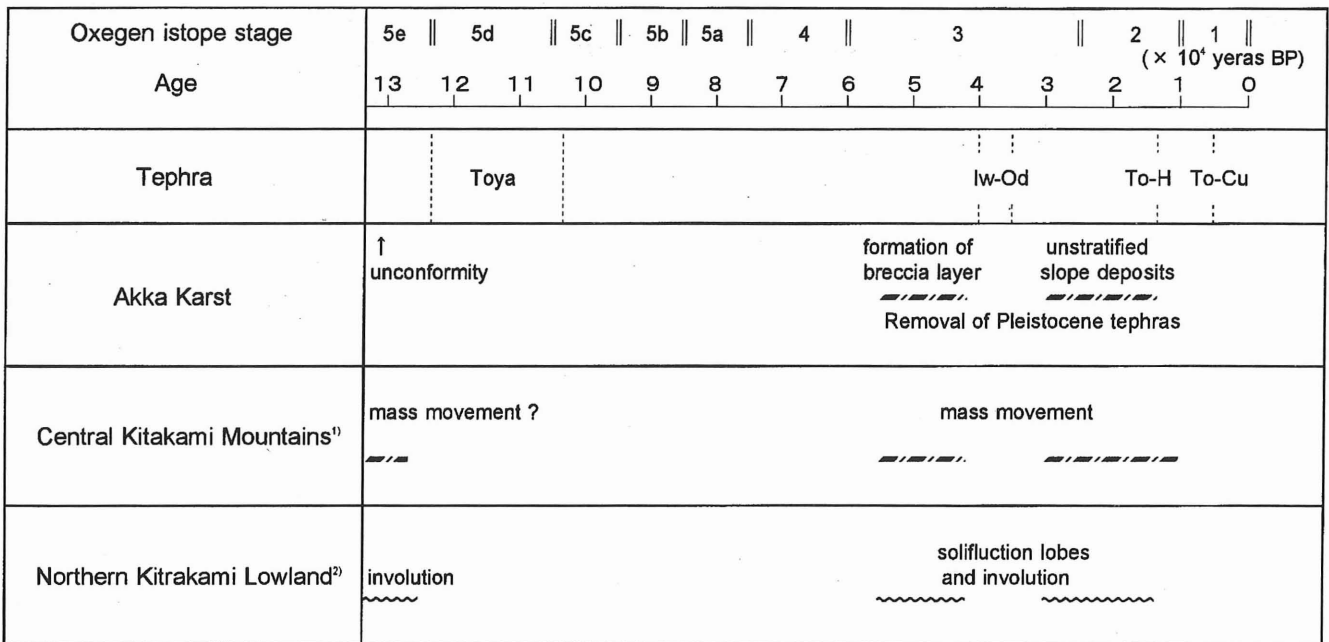


FIG. 7 - Geomorphic events in the late Quaternary in the Akka Karst, Central Kitakami Mountains and Northern Kitakami Lowland. 1) Higaki (1987), 2) Okami & Doi (1978), Inoue & *alii*, (1981) and Sawaguchi (1992).

content of biotite, which is not included in either the residuum of Akka Limestone or the identified tephras. Biotites were presumably transported by wind from granitic mountains adjacent to the Akka Limestone, because granitic rocks include many biotites as rock-forming minerals and the karstic plateau is entirely dissected by rivers from a non-limestone area (fig. 2). Therefore, bare ground affected by periglacial processes should have been distributed over the summits of granitic mountains during the late Pleistocene. Gentle slopes on the summits of granitic mountains gradually became stable after the falling of To-H, which lasted until the early Holocene, because biotites are absent in soils above To-H on the limestone plateau and To-Cu (5.5 ka BP) is found on the gentle slopes on the summit of Mt. Toshima (fig. 2) near the Akka Karst (Ikeda & Daimaru, 1993). As stated above, allogenic deposits on karst have helped to reconstruct environmental conditions in non-limestone areas as well as in limestone areas.

To-Cu is absent on the steep slopes and is present as patches on the gentle slopes, although it is found about 30 cm in thickness at the bottom of dolines or at the foot of slopes. This implies slope instability after the To-Cu fall. According to Yoshinaga & Koiwa (1996), slope development in the forested mountains in Japan changed rapidly during the latest Pleistocene to Holocene, due to a climatic transition from cold and relatively dry conditions to temperate and humid conditions, and especially due to an increasing frequency and intensity of storms. Thus, during the Holocene in the study area, soil creep has probably occurred on the gentle slopes, whereas the removal of regolith has frequently happened on the steep slopes. Moreover, soil erosion would have been accelerated by forest clearance and subsequent conversion of forest to grassland, followed by human exploitation of the Akka Karst.

Fig. 7 shows geomorphic events with emphasis on periglacial processes in the late Quaternary in the Akka Karst, the Central Kitakami Mountains and the Northern Kitakami Lowland Area. The formation periods of periglacial deposits in the Akka Karst correspond with those of mass movement by periglacial processes in the Central Kitakami Mountains, and of involution and solifluction lobes in the Northern Kitakami Lowland. In the study area, Pleistocene tephras on the slopes were mainly removed by periglacial processes under the cold climate during the Last Glacial Stage. In order to obtain a more detailed reconstruction of environmental changes in the Akka Karst, it is necessary to compare the deposits of slopes, dolines and caves, and to date their ages.

CONCLUSIONS

This paper has discussed fossil periglacial phenomena in the Akka Karst, northeastern Japan, on the basis of tephrochronological investigations. On the karstic plateau, there are some fossil periglacial deposits which were presumably formed around 50 ka BP and 30 ka BP. Pleistocene tephras are absent on the slopes in the study area as result

of periglacial processes, such as solifluction and frost shattering of limestone bedrock, in the cold phases of the Last Glacial Stage. The periods of slope evolution by periglacial processes are considered to be around 50 ka BP and from 30 to 10 ka BP, which are in accord with those of mass movement in the Central Kitakami Mountains, and of involution and solifluction lobes in the Northern Kitakami Lowland. The high content of biotite, which originated from granitic rocks, in soils in the bottom of dolines on the karstic plateau implies that bare ground affected by periglacial processes was distributed over the summits of granitic mountains adjacent to the Akka Limestone during the late Pleistocene. Accordingly, allogenic deposits on karst have helped to reconstruct environmental conditions in non-limestone areas as well as in limestone areas.

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