Regolith Slide Recurrence History Indicated by Radiocarbon Ages in the Hills around Sendai , Northeastern Japan

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Regolith Slide Recurrence History Indicated by Radiocarbon Ages in the Hills around Sendai, Northeastern Japan

Ying LI* and Toshikazu TAMURA**

Abstract Observation of actual rain-induced regolith slides in the hills around Sendai confirmed that slides were concentrated on particular geomorphic positions and that deposits of slide itself and induced debris flow overlay the humic topsoil on some hillslopes or bottomlands. Then radiocarbon dating was systematically applied to buried humic topsoil horizons overlain by former slide deposits or debris flow deposits on bottomlands and head hollows in order to reconstract the history of regolith slide occurrence in a watershed. It was concluded that regolith slides have repeated at an interval of 300 to 400 years during at least recent 1,000 years on relatively slide-prone segments of a watershed, while the interval is about 2,500 years on relatively stable segment. The knowledge will contribute to the consideration of hillslope development rate controled chiefly by regolith slides under temperate monsoon climate which has been prevailing since the early Holocene in Northeastern Japan.

Key words: Regolith slide, Recurrence history, Hillslope development, Radiocarbon dating, Heavy rain

1. Introduction

Rain-induced regolith slides are considered the most effective processes to develop hillslopes in the temperate monsoon climate. This study aims at reconstructing the recurrence history of regolith slides on hillslopes which are segmented by breaks. It will contribute to the study of hillslope development in the above-mentioned morpho-climatic condition which has been prevailing since, at least, the early Holocene in Northeastern Japan. For this purpose, radiocarbon dating was applied to humic soil horizons overlain by deposits which were produced and transported by former slides and following debris flows in the hills around Sendai.

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2. The case of the Tomiya Hills

About 2,000 regolith slides were induced by a heavy rain amounting to 400 mm in 30 hours in a area of about 10 km^2 in the southeastern part of the Tomiya Hills, north of Sendai, on 5 August 1986 (Fig. 1) (Tamura and Miyagi, 1987). The Tomiya Hills are mostly composed of semiconsolidated sandstone of the Miocene and their slopes consist of twelve micro-scale geomorphic units (Tamura, 1987, 1996) which are combined to the upper and the lower segment (Fig. 2 and Table 1). Detailed study of the distribution of slide-heads revealed that most slides are distributed on the lower segment which shows slope angle of 35 to 60 degree (Tamura, 1987, 1996). The spatial frequency of slide heads on each segment has been measured by the use of GIS technique (Chatterjee, 1999). The typical slides occurred in the Tomiya Hills in August 1986 have their heads on, or immediately below, the convex break of slope which separates the upper and the lower segment. Regolith less than 1m thick was

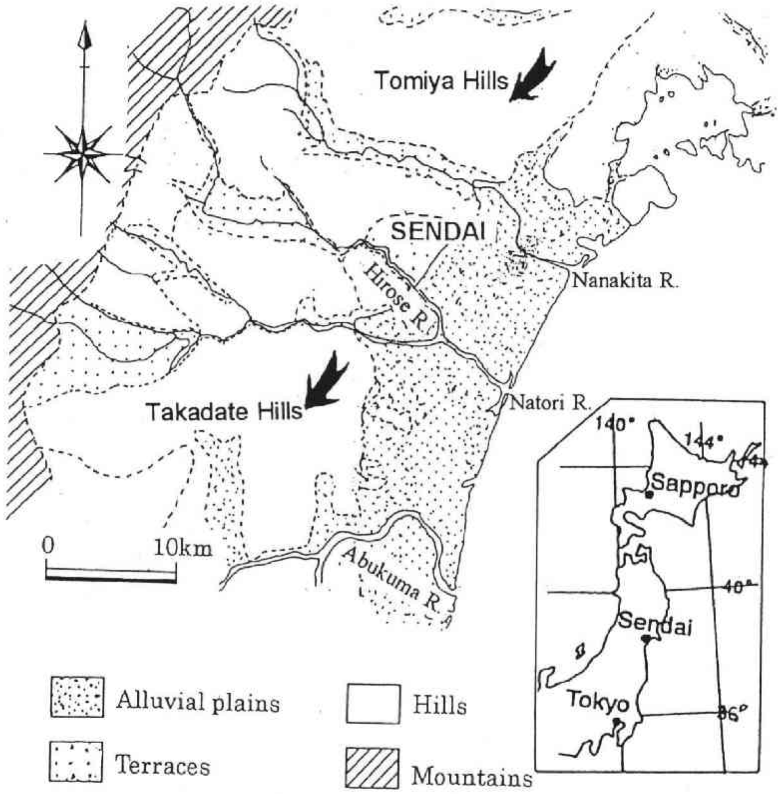

Fig. 1 The areas studied

removed from the heads. Volume of debris produced at a slide site is less than 1,000 m^3 in most cases. Removed regolith material admixed with water rapidly slided down and was deposited to form a small talus at the foot of the lower sideslope or flowed further downstream on the bottomland, together with that from other slides, as sandy

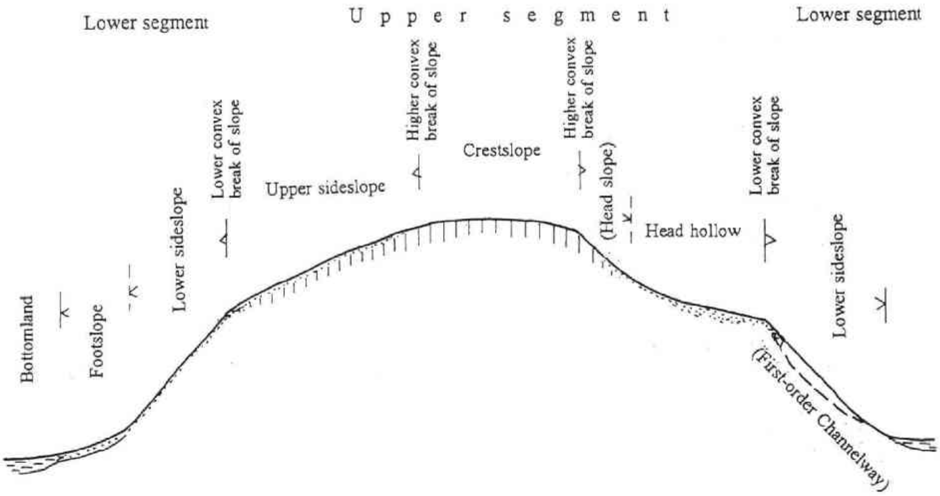

Fig. 2 A schematic profile of hillslopes classified to micro-scale geomorphic units and combined to upper and lower segments

Table 1 Micro-scale geomorphic units composing hillslopes (Tamura, 1996, sligthly modified)

		Micro-scale geomorphic units
Crest	UPPER SEGMENT	Crest flat Crest slope
Hill-side	UPPER SEGMENT	Upper sideslope Upper side-hollow Head slope Head hollow
Hill-side	LOWER SEGMENT	Lower sideslope Lower side-hollow
Hill-side	LOWER SEGMENT	Footslope Small terrace surface
Valley floor		Bottomland Channelway

debris flow. Both talus and debris flow deposits covered the former humic topsoil on the bottomlands (Fig. 3) (Tamura, 1987).

In a second-order watershed which is different from that shown in Fig. 3 and about

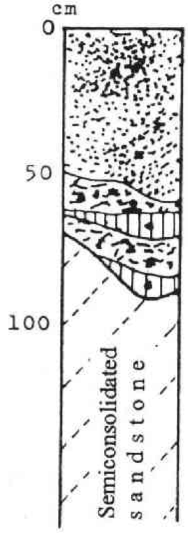

Fig. 3 A regolith profile on the bottomland of a amall second-order watershed where 16 regolith slides occurred on the lower segments in August 1986. (Extracted from Tamura, 1987)

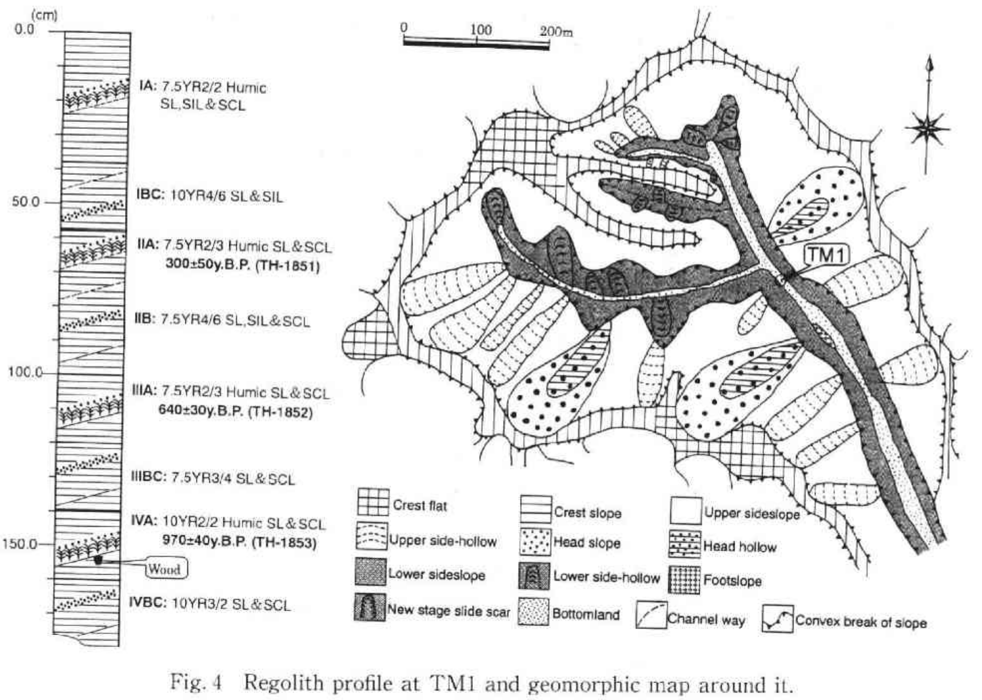

Fig. 4 Regolith profile at TM1 and geomorphic map around it.

20 ha in area, we can recognize about ten regolith slide scars on the lower segments which did not suffer from slides in the 1986 event. At TM1 on the bottomland, three black humic horizons are respectively overlain by brown sandy or loamy layers which seem to have been provided from regolith slides situated on the lower segments upstream (Fig. 4). In consideration of both the occurrence pattern of regolith slides in the other watersheds in the 1986 event and the distribution of former slide scars in the watershed, the regolith profile at TM1 is interpreted as the record of repeated sudden burial of humic topsoil by debris which was produced by regolith slides mostly on the lower segments. The radiocarbon dating has been applied to humus or contained woods in the three buried humic horizons. The results are 300±50 y.B.P. (TH-1851), 640±30 y.B.P. (TH-1852), and 970±40 y.B.P. (TH-1853), respectively from the upper (Fig. 4). At TM2 on the bottomland of the other second order watersheds which is about 8ha in area and contains about ten regolith slide scars on its lower segments, one buried humic horizon is recognizable below a gleied debris layer. The radiocarbon dating of humus of the buried A horizon gave the age 390±30 y.B.P. (TH-1849) (Fig. 5). These ages suggest that regolith slides recurred at the interval of about 300 to 400 years on the lower segments of the second-order watersheds in the Tomiya Hills, during at least recent 1,000 years.

A trench on a head hollow (TM3) situated on the upper segment of the first-order watershed exhibits two buried A horizons overlain by clay-loamy colluvial layers.

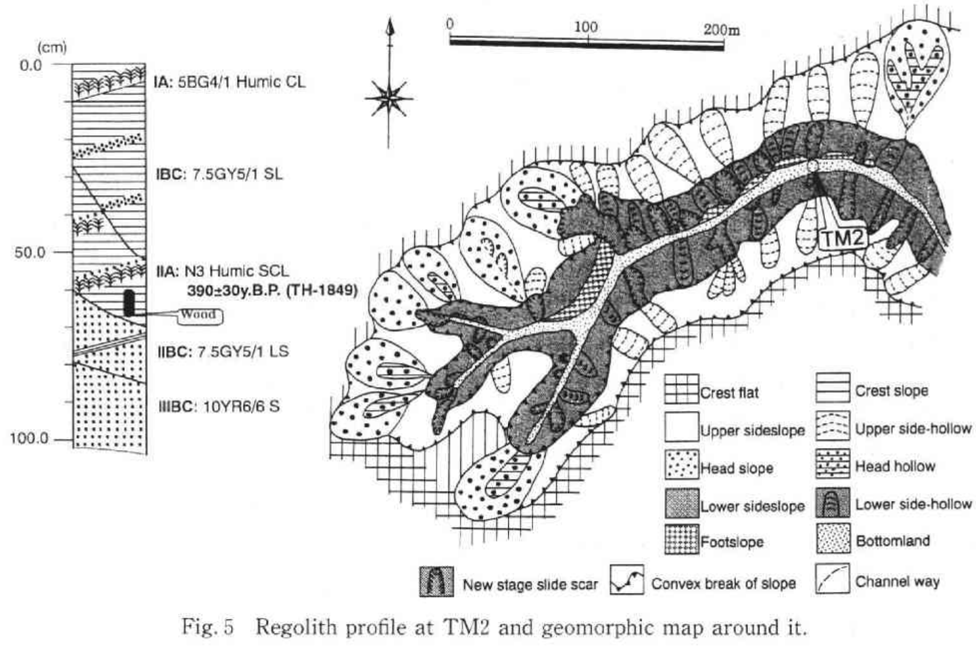

Fig. 5 Regolith profile at TM2 and geomorphic map around it.

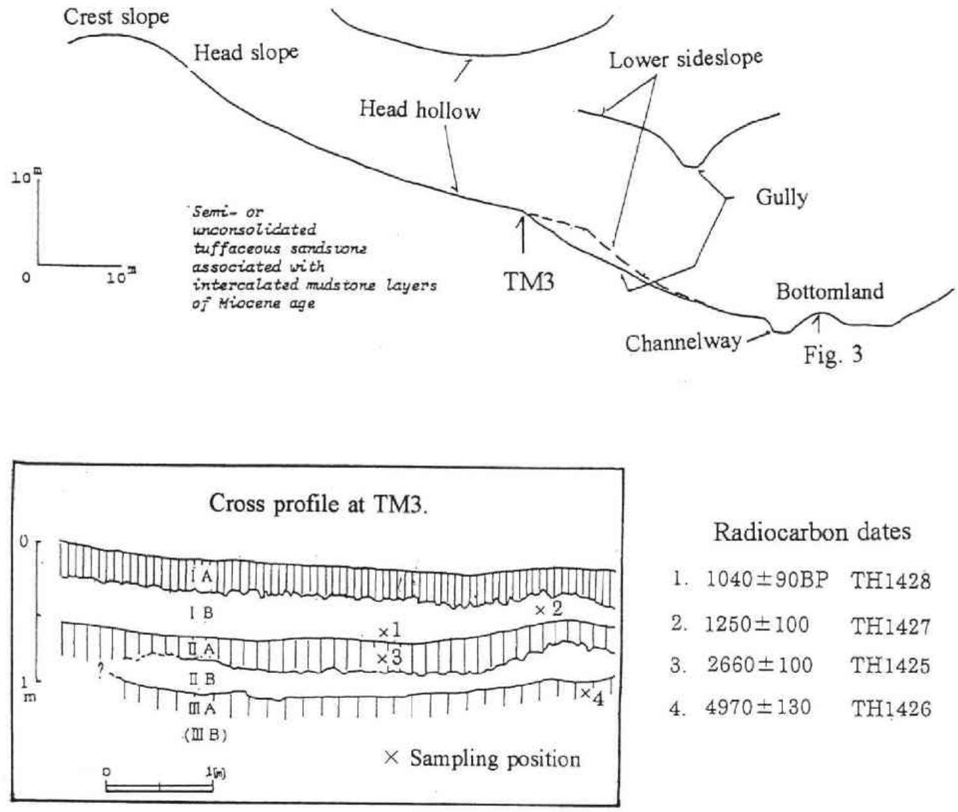

Fig. 6 Regolith profile at TM3 and geomorphic profile around it.

Handy penetration test on the side of the trench reveals that the thickness of regolith is over 3 m and the upper 2 m is of transportational, namely colluvial in this geomorphic position, origin (Fig. 6). Radiocarbon ages of the humus of the upper and the lower buried A horizon are 2,660±100 y.B.P. (TH-1425) and 4,970±130 y.B.P. (TH-1426), respectively. It means that the head hollow recurrently received slided debris from the surrounding head slope and/or upper side slope, 20 to 30 degree, at the interval of about 2,200 to 2,700 years or more during at least the last 5,000 years. The average interval of slide occurrence on the upper segments is thus obviously longer than, about 6 to 9 times of, that on the lower segments.

3. The case of the Takadate Hills

More than 1,000 regolith slides were induced by a localized heavy rain amounting to 500 mm in 20 hours on 22 to 23 September, 1994, in the central and the northern part

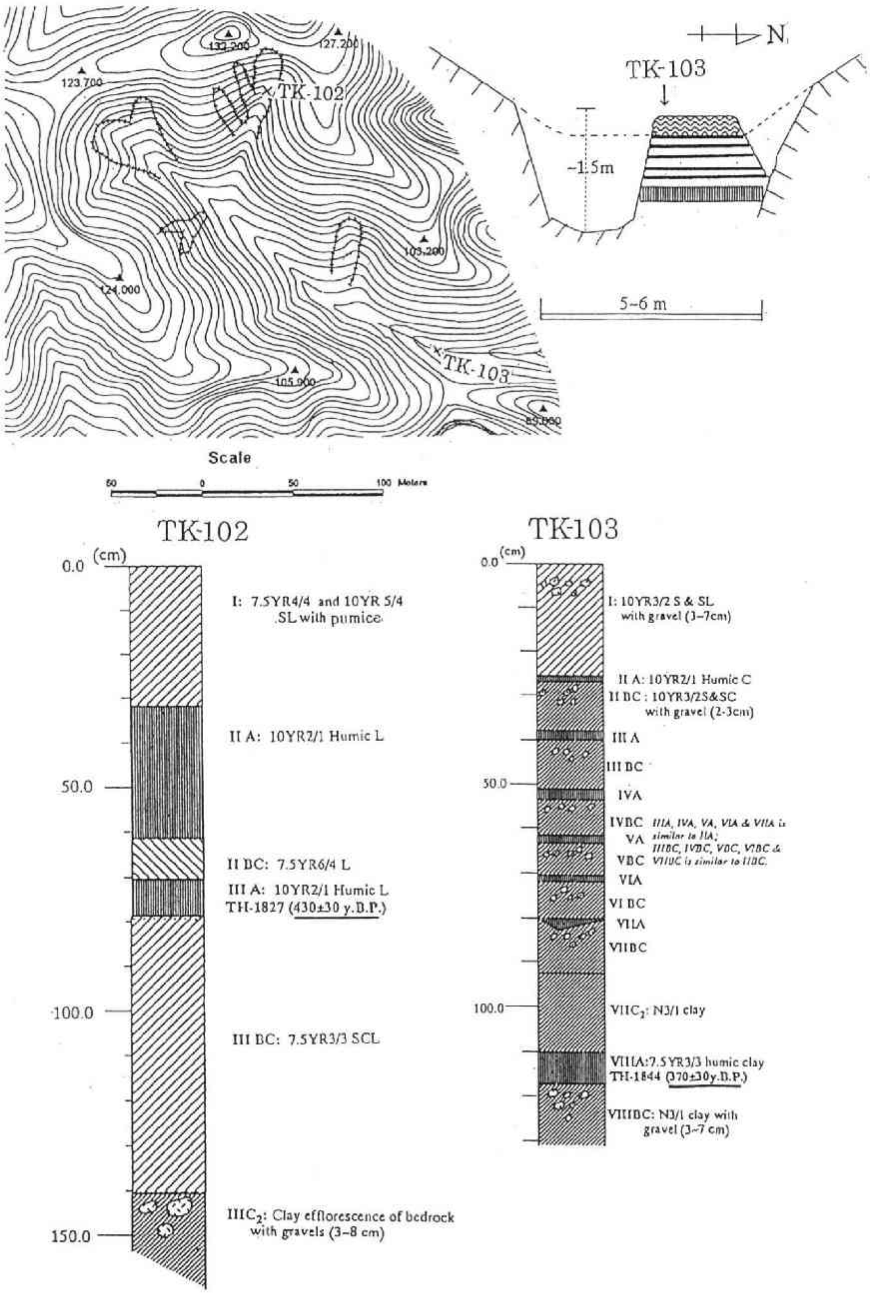

Fig. 7 Topographic map of TK1 and regolith profiles at TK102 and TK103

of the Takadate Hills, south of Sendai (Tamura *et al.*, 1995). In contrast to the case of the Tomiya Hills in 1986, regolith slides occurred in the Takadate Hills in 1994 are concentrated on the upper segment, particularly on the headmost walls (Chatterjee *et al.*, 1995). Spatial frequency of regolith slides on the lower and the upper segment has been measured by the use of GIS technique (Chatterjee, 1999) and the causes of the different occurrence of regolith slides in the two cases have been discussed in their relation to the development of hillslopes with different lithology (Tamura *et al*, 1999). Depth of slide is less than 1 m and volume of debris produced in a slide site is less than 1,000 m^3 except two slides which are situated on the former deep-seated slide (Tamura *et al.*, 1995 : Tamura, 1997). Most of slided material was rapidly transported downstream as debris flow and very thin deposits remained on head hollows and upper sections of bottomlands.

Eight regolith slides occurred on the upper segments in TK1 which is a second-order watershed about 3 ha in area situated in the eastern part of the Takadate Hills (Fig. 7). Slided material was clay to loam in texture, which was deeply weathered andesite exposed extensively on the upper segments of the watershed. At TK102 on a head hollow about 20 m beneath the slided headmost wall which shows the maximum slope angle of 55 degree, two buried humic horizons are recognizable and the upper one is obviously covered by 30cm thick debris of the 1994 slide (Figs. 7 and 8). The lower one, which is considered to have been buried by debris at the preceding slide event,

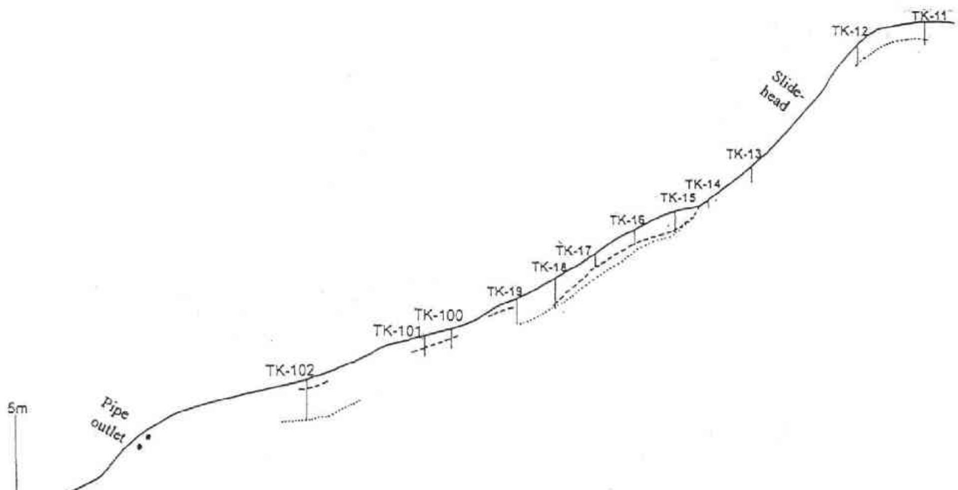

Fig. 8 Geomorphic profile of the valley head around TK102
Dotted line and broken line indicates the bottom of regolith and the bottom of 1994 debris, respectively.

gave a radiocarbon age of 430 ± 30 y.B.P. (TH-1927).

At TK103 on the narrow channel bottom about 250 m downstream of TK102, we can observe thin alternation of sandy-loamy deposits with or without angular gravel and humic swampy deposits below the 1994 debris flow deposits about 25 cm thick (Fig. 7). It indicates the recurrece of debris flows in the watershed. Among the former debris flow deposits, a relatively thick layer with very few gravel seems to be the direct result of the slides on the upper segments where deeply weathered andesite is exposed, and thin gravelly layers are considered to show secondary removal of former slide deposits remained on the bottomlands. The latter were mixed with rubble stripped off from the channel bottom where fresh andesite is exposed. Radiocarbon dating was applied to a comparatively thick humic layer which is 85cm below the 1994 debris flow deposits and overlain directly by the thickest debris flow deposits on the profile. The result is 370 ± 30 y.B.P. (TH-1844).

The two radiocarbon ages obtained from the watershed TK1 indicate that the concentrated landslide event preceding to the 1994 event took place about 400 years ago on the upper segment, probably headmost wall, in the watershed. The interval is equivalent to that revealed in the lower segments of the Tomiya Hills.

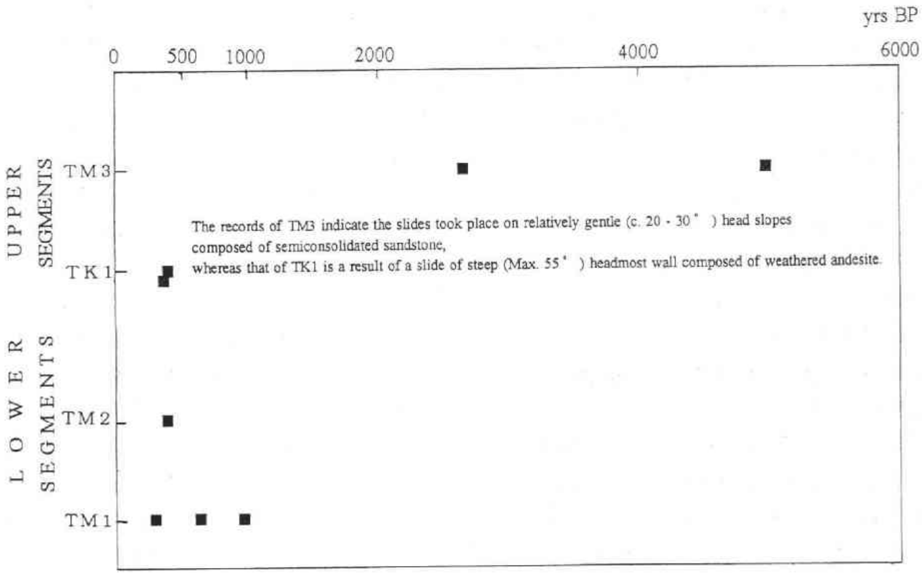

Fig. 9 Recurrence history of regolith slides indicated by radiocarbon ages which were obtained from humic soils buried abruptly by debris in several geomorphic positions

4. Discussion

In the Tomiya Hills where rain-induced regolith slides were concentrated on the lower segments in the 1986 event, three radiocarbon ages obtained from different horizon of a columnar section (TM1) on the bottomland of a second order watershed and one age from similar topographic situation of the other second-order watershed (TM2) have revealed that regolith slides have repeated on the lower segments of the same watershed at an interval of 300 to 400 years during at least recent 1,000 years. In the Takadate Hills where rain-induced regolith slides were concentrated on the upper segments in the 1994 event, a pair of radiocarbon ages obtained from a second-order watershed (TK1) showed that about 400 years is the interval of the last two regolith slide events occurred on the upper segments of the watershed (Fig. 9).

The above facts tell that the average recurrence period of regolith slides is about 300 to 400 years during at least last 1,000 years in a second-order watershed in the investigated hills. On the other hand, a pair of radiocarbon ages obtained from the deposits of the head hollow TM3 in the Tomiya Hills suggest 2,200 to 2,700 years or more as a recurrence period of regolith slides during at least the last 5,000 years on the upper segments, where no regolith slide occurred in the 1986 event (Fig. 9).

The recurrence interval of regolith slides is considered to be controlled by the frequency of heavy rain which can induce slides and the rate of regolith growth which can respond to heavy rain (*e.g.*, Iida, 1989). Previously reported recurrence intervals of regolith slides in various areas of Japan range from thousands to several tens of years (*e.g.*, Yoshinaga *et al.* 1989 ; Yanai, 1989 ; Shimokawa *et al.*, 1989). Using dendrochronology and historic records, Shimokawa, *et al.* (1989) reported the interval of about 70 years on the cliffs composed of slide-prone pumice flow deposits in South Kyushu which receives frequent heavy rain provided chiefly by typhoon. Tephrochronological study in Central Hokkaido, where both rainfall intensity and frequency of slide-inducing rain are much lower than South Kyushu, revealed the interval of several hundred years on the lower segments covered by air-borne tephra (Yanai, 1989).

The interval about 300 to 400 years presented by this paper is considered to be applied to the slide-prone slope segments of the hills composed of semiconsolidated sedimentary or deep weathered volcanic rocks of mostly Neogene age in Northeastern Japan. At the same time, it should be remarked that much longer interval of regolith slide occurrence, around 2,500 years, is applicable to the slopes which are not so prone to slides in the same hills. The difference in the interval is interpreted to reflect first the difference in the accumulation of removable regolith on each topographic position, because rainfall and rainfall intensity are not considered so different by topographic position in a small area.

Preliminary investigation of recurrence interval of rainfall in an hour, one day and two days in the two cases suggest that it is shorter than the recurrence interval of landslides as mentioned above (Sano, 1999). The contrastive concentration of regolith slides on the lower and the upper segments in the event of the Tomiya Hills in 1986 and that in the Takadate Hills in 1994, respectively, provides a problem which should be further investigated in consideration of morphometry, lithology, shallow subsurface water and groundwater hydrology, and hillslope development. It will be discussed separately (Tamura *et al.*, 1999).

Climatic humidification in accordance with warming since the end of the Pleistocene in most areas of East Asia is expected to have increased the frequency of heavy rain and then of landslide (*e.g.*, Moriya, 1972 ; Kaizuka, 1980). It has been discussed in connection with the development of the lower segments of hillslopes (*e.g.*, Hatano, 1974 ; Tamura, 1996). Although we will prepare the other paper (Tamura *et al.*, 1998) on the contribution to the climatogenic geomorphological and paleohydrological studies, this paper will contribute to present the average condition of rain-induced regolith slide occurrence in the hills composed of Tertiary rocks under temperate monsoon climate which has been prevailing since the early Holocene.

In addition, this paper demonstrates that radiocarbon dating of not only slide deposits but also valley bottom sediments is effective for the investigation of reccurence history of landslides in the watershed if the regolith profiles are appropriately interpreted with careful reference to actual occurrence of slides.

5. Conclusion

Radiocarbon ages of buried humic horizon on bottomlands and head hollows have been interpreted on the basis of the occurrence pattern of actual rain-induced regolith slides in the hills around Sendai. It is thus concluded that regolith slides have repeated on relatively slide-prone segments of a second order watershed at an interval of 300 to 400 years during at least recent 1,000 years, while the interval is about 2,500 years on relatively stable segment in the same hills. The average reccurrence intervals will contribute to the consideration of hillslope development rate controled chiefly by regolith slides under temperate monsoon climate which has been prevailing since the early Holocene in Northeastern Japan. It remains for further hydrogeomorphic analysis in consideration of morphometry and lithology that the slide-prone segment is the lower in a hilly area and the upper one on the other.

Most of this paper is based on a part of Ying Li's doctoral thesis submitted to Tohoku University in 1997. Some parts of this paper were already reported in several conferences (Li *et al.*, 1996 ; Tamura *et al.*, 1998 ; Tamura *et al.*, 1999). Radiocarbon dating was made by Li using a liquid scintillation system equipped in the Institute of Geography, Tohoku University, under the guidance of Dr. Shin-ichi Hirano. Field observation and sampling were carried out by the assistance of many students of the Institute in those days, particularly Dr. Taku Komatsubara presently at Geological Survey of Japan, Dr. Takeya Yoshiki presently at Kyoto University, and Mr. Takeshi Matsubayashi. Many discussions and suggestions were given by many staff members and students of the Institute, particularly Dr. Hideaki Matsumoto, Dr. Kiyotaka Sakaida, Dr. Yoshinori Otsuki and Mr. Hisashi Sano. We would like to express sincere gratitude to them.

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