Geomorphological Features of Avalanche Furrows in Heavy Snow Region in Japan

Tatsuo SEKIGUCHI, Hiroshi P. SATO and Kazuya AKIYAMA [1]

Abstract

The occurrence of full-depth snow avalanches (FDSAs) on slopes in Japanese mountain areas is indicated by narrow straight scratch patterns, called "avalanche furrows", on aerial photographs. Avalanche furrows show a semicircular or U-shaped transverse profile as if they had been scored by a round chisel. They have a width of 2-4 m and a depth of 1-3 m and occur mainly on slopes with a 35°-45° inclination. Avalanche furrows are exposed on a smooth surface of bedrock and show striae produced by FDSAs.

Aerial-photo interpretation over Japanese Islands shows that avalanche furrows are mainly distributed from Hokkaido to the Chugoku Mountains along the Japan Sea coast. The distribution of avalanche furrows corresponds to mountains with deep snow cover over 2 m and increases with altitude. In other countries, wet snow avalanches occur mainly in polar and alpine areas with much colder climates. In contrast, FDSAs occur in temperate climates and at altitudes as low as 300 m in Japan. The major factors controlling the formation of avalanche furrows in Japan are considered to be the temperate climate, heavy snowfall, steep slopes and poor vegetation.

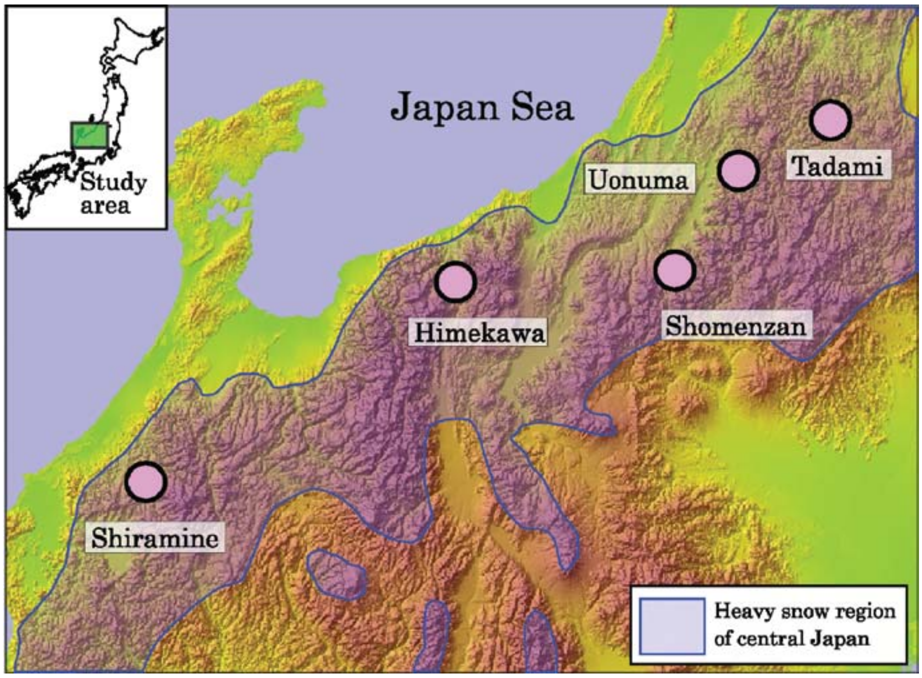

Fig. 1 Study area

1. Introduction

The snow depth reaches several meters in snowy seasons in Japanese mountain areas. Full-depth snow avalanches (FDSAs) occur on slopes covered with deep snow and erode the slope surface (Sekiguchi, 1994 ; Sekiguchi & Sugiyama, 2003). Many tree blocks, earth and sand involved in the avalanche debris indicate progressive erosion of the slope surface by FDSAs (Rapp, 1960; Luckman, 1977; Gardner, 1983; Ackroyd, 1986). Slopes subjected to FDSAs reveal straight scratched furrows in bare ground or surrounded by grasses and shrubs, while they lack tall trees. These slopes can be easily identified on aerial photographs (Sugiyama et al., 1987; Butler et al., 1992).

Shimokawa (1980) called slopes subjected to FDSAs "avalanche chutes". These show a shallow,

[1] Niigata Experimental Laboratory, Public Works Research Institute

concave cross profile with a width of 30-50 m, and a longitudinal length of 200-500 m, vegetation-free bedrock exposure and 35°-45° inclination. Luckman (1977) and Butler (1992) described "avalanche paths" or "avalanche tracks" which are narrow and show linear morphology caused by wet snow avalanches in Scandinavia, Montana (USA) and Alberta (Canada). All of these linear features are formed by FDSAs or wet snow avalanches.

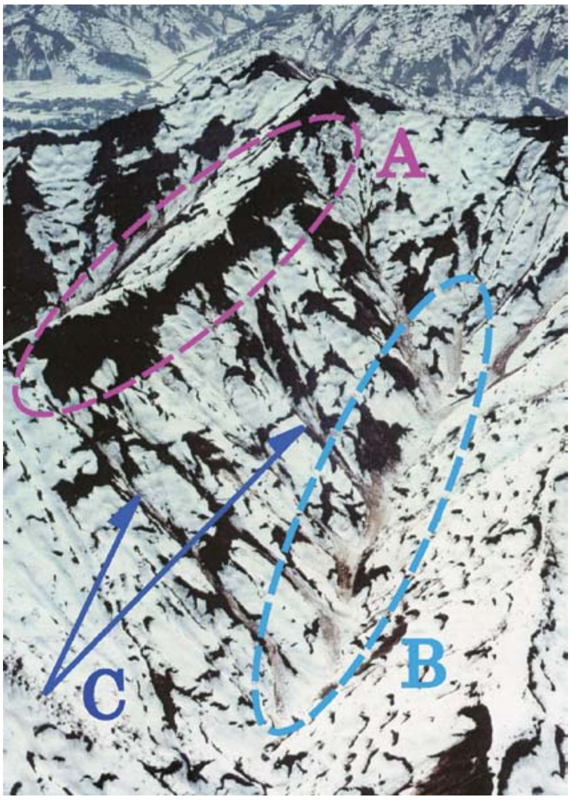

Fig. 2 Aerial photograph of slopes subjected to full-depth snow avalanches in Uonuma area. A : FDSA starting area B : avalanche deposit area C : avalanche furrow (March 1989, by the Geographical Survey Institute).

In addition to the avalanche chutes described by Shimokawa (1980), many similar straight, but much smaller furrows are widely distributed in mountain areas with heavy snowfall in Japan. These narrow straight furrows, both sides of which are fringed with shrubs, are several meters in width and occur in exposed bedrock. These slopes have similar inclinations to avalanche chutes and occur in similar or lower altitudes than the latter. Miyazaki (1937) called these straight furrows "Lawinen Zug". He reported that "Lawinen Zug" are distributed on slopes where FDSAs occur every year. Sugiyama et al. (1987) and Sekiguchi (1994) defined these furrows as "avalanche furrows" which show straight patterns on aerial photographs taken in snow-free periods.

The purpose of this paper is to show that avalanche furrows are closely related to FDSAs and that their distribution corresponds to heavy snowfalls. Factors affecting avalanche furrows are also discussed.

Fig. 3 Avalanche debris with FDSA in Mt. Gongendake (May 2003, by the authors) .

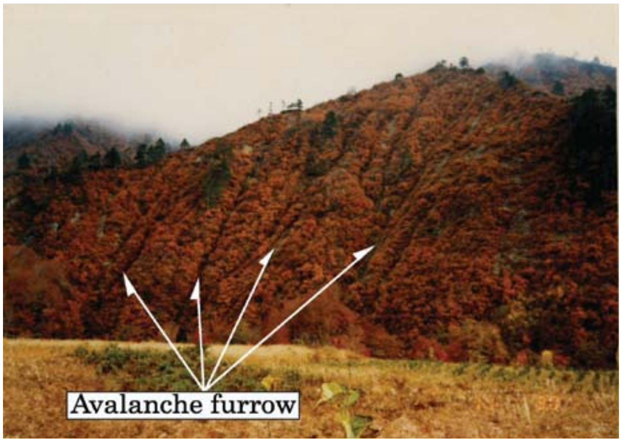

Fig. 5 View of avalanche furrow in Tadami area (November 1985, by the authors). Many avalanche furrows are seen among the shrubs.

The study areas are located in the Japanese backbone ranges facing the Japan Sea coast (Fig. 1), where the snow depth reaches 2-4 m during winter and FDSAs frequently occur in spring. The study involves analysis of geomorphological features, such as the inclination of FDSA-affected slopes and the relationship between FDSAs and avalanche furrows in the three sample areas of Uonuma, Himekawa and Shiramine. Aerial-photo interpretation and field survey were also undertaken in the Shomenzan and Tadami areas in the Hokuriku regions to illustrate features of avalanche furrows, such as ground surface conditions and direction. Furthermore, the distribution of avalanche furrows was investigated on a regional scale, using aerial photographs all over Japan.

Fig. 4 Avalanche furrows in the Uonuma area; aerial photograph , taken during a snow-free period (September 1976, by the Geographical Survey Institute). Possible use stereo vision with 3D.

(a) Upper part of an avalanche furrow (b) Middle part of an avalanche furrow

Fig. 6 Ground surface of the upper and middle part of an avalanche furrow in the Tadami area (November 1991, by the authors). Inclination is 40°, and slope direction is southwest.

2. Characteristics slopes subjected to full-depth snow avalanches

Figure 2 shows typical slopes subjected to FDSAs. A FDSA starts near the top of a ridge, runs out on a slope and finally deposits at the foot of the slope as a snow-debris cone (Onodera, 1974). In Japan, FDSAs occur on steep slopes during the snow melting period in spring, when air temperatures rise above 0°C. A FDSA is generated when the snow depth reaches more than 2 m on slopes covered mainly with shrubs. The collapsed snow mass gradually changes into fluid, flowing down the slope leaving the bedrock exposed. Many tree blocks, earth and sand are involved in the avalanche debris caused by FDSA (Fig. 3).

3. Morphology of avalanche furrows

Avalanche furrows display straight scratched patterns on aerial photographs in snow-free periods (Fig. 4). Figure 5 shows a typical example of the FDSA-affected slopes. The bottom of a furrow usually exposes bedrock and both sides of the furrow are partly covered with grasses and shrubs. Avalanche furrows have a semicircular or U-shaped cross profile as if they had been formed by a round chisel, with a width of 2-4 m and a depth of 1-3 m (Fig. 6). The upper and middle parts of the avalanche furrows show very smooth surfaces with many striae produced by FDSAs. In the field, these striae have a length of 0.5-2 m, a width of 1-3 cm and a depth of 0.5-2 cm. These features indicate that erosion by FDSA is active, and that avalanche furrows are produced by FDSA.

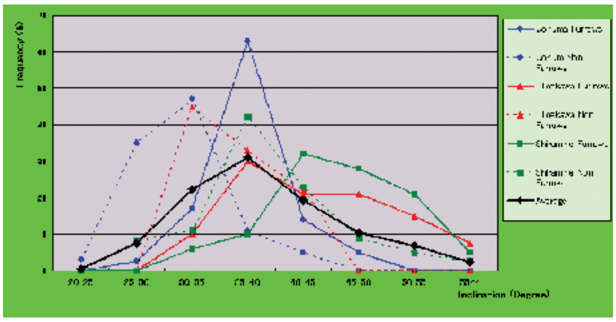

Fig. 7 Inclination of FDSA-affected slopes. Locations are shown in Fig. 1.

4 Local distribution of avalanche furrows

4.1 Slope inclination

Figure 7 compares the inclination of slopes with avalanche furrows and those without avalanche furrows where FDSAs occurred. The inclination is divided into 5° intervals. Inclinations of avalanche furrows range from 35° to 45°, whereas those of slopes without avalanche furrows mostly lie between 25° and 40°. The latter is significantly gentler than the former. In addition, inclinations of these avalanche furrows are similar to those of avalanche tracks reported by Rapp (1959) and avalanche chutes by Shimokawa (1980).

4.2 Direction

Figure 8 shows directions of avalanche furrows in the Tadami, Shomenzan and the three sample areas. Data are based on aerial photographs either in snow avalanche periods (the three sample areas) or in snow-free periods (the other two areas). The prevailing directions are to the west and south in the three sample areas. Avalanche furrows are rarely seen on the north and northeast-facing slopes of shaded parts where most of the FDSAs may occur at a later period. In fact, aerial photographs in these sample areas taken during the period of FDSA occurrence indicate that FDSAs most frequently occurred on the west and south slopes. Thus, data from these three areas may not show the actual prevailing directions. In contrast, the prevailing directions are east to northeast in Tadami and Shomenzan areas where avalanche furrows could be seen over all directions as they were mapped from aerial photographs in the snow-free period.

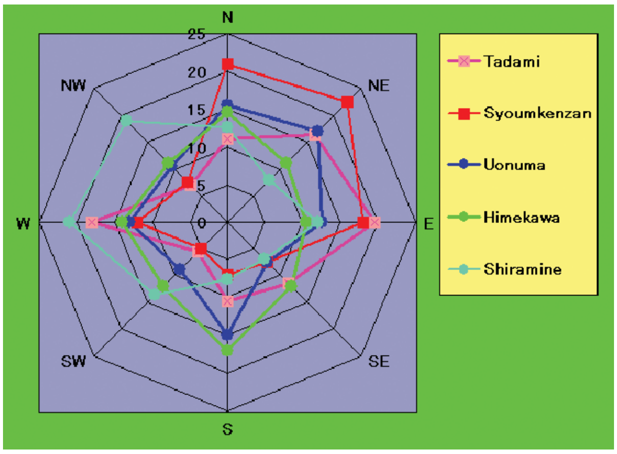

Fig. 8 Directions of avalanche furrows on slopes subject to full-depth snow avalanches locations are shown in Fig. 1.

Mountain ranges in Japan mostly lie in a north to south direction. The prevailing northwesterly or westerly winds in winter form cornices projecting toward eastern slopes, which allow avalanches to occur easily to the east (Shimokawa, 1980 ; Fig.9). Butler (1979) reported that directions of avalanches are mainly to the northwestern, southeastern and southern aspects in Montana. These conditions suggest that the direction of snow avalanches are significantly affected by the regional topography that determines the aspect of slopes, as well as sunshine and the directions of the prevailing wind.

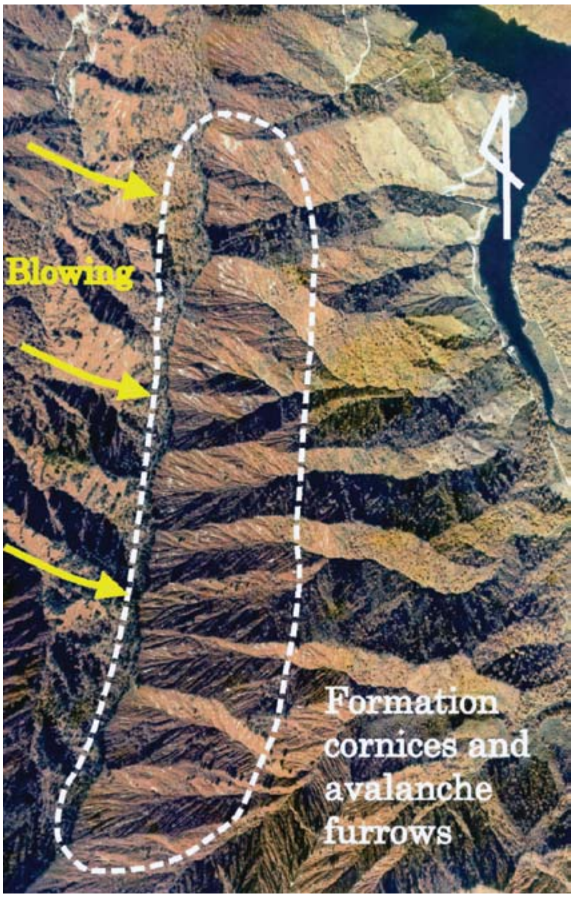

Fig. 9 Aerial photograph of avalanche furrows in Tadami area, taken during snow-free period (September 1976, by the Geographical Survey Institute). The direction of Japanese mountain ranges lays N-S. In this photo, the directions of avalanche furrows are mainly to the east,

5. Regional distribution of avalanche furrows in Japan

5.1 General characteristics

Figure 10 shows the general distribution of avalanche furrows in Japan, based on aerial photographs taken in snow-free periods. Avalanche chutes as described by Shimokawa (1980) have also been included in the avalanche furrow areas, as they mostly occur in the same areas. Avalanche furrows are mainly distributed on mountains along the Japan Sea coast, with a concentration in the southern Tohoku and Hokuriku regions and sporadic distribution in Hokkaido, northern Tohoku and Chugoku regions. In contrast, they are distributed only on high mountains such as the Kitakami Mountains, southern Japanese Alps and Shikoku Mountains along the Pacific side (Sekiguchi, 1994; Sekiguchi, 2001 ; Sekiguchi & Akiyama, 2002 ; Sekiguchi & Akiyama, 2003; Sekiguchi & Akiyama, 2004).

5.2 The effect of altitude

Figure 11 shows changes in the occurrence frequency of avalanche furrows with altitude along the survey lines drawn in Fig. 10. The survey lines show transverse profiles from the Japan Sea coast toward the Pacific coast in five regions. Along each line, mountains were classified in terms of altitude as low (approx, 500m), middle (approx, 1000m) or high (approx, 2000m), in which the numbers stand for the altitude of each region and each survey line.

In Hokkaido and the northern Tohoku regions, the frequency is only 20 % on the low mountains and 50 % on the high mountains, but it increases to 70 % on the middle and high mountains in the southern Tohoku and western Hokuriku regions. The frequency is highest over all elevations in the eastern Hokuriku region, reaching 85-95 % on the high mountains. Therefore, the occurrence frequency generally increases with altitude and is highest in the Hokuriku region.

6 Discussion

6.1 Formative factors of avalanche furrows

The distribution of avalanche furrows is generally correlated with areas subjected to snow depths of greater than 2 m (see Fig. 10). This suggests that heavy snowfalls cause FDSAs and form avalanche furrows. Heavy snowfalls on the Japan Sea coast originate from northwesterly winds in winter, which contain abundant moisture (water vapor) after traversing the Japan Sea. This moisture content is cooled rapidly when rising over mountains, resulting in high snowfall. In mountain areas, the seasonal snow cover reaches over 2 m, and this becomes the primary determinant of the occurrence of FDSAs and formation of avalanche furrows (Sekiguchi, 1994).

Steep Japanese mountain slopes are the second factor of the avalanche furrow formation. Slopes with avalanche furrows occur mostly on mountain sides. Sekiguchi & Sugiyama (2003) reported avalanche furrows occur also on landslide scarps, river terrace scarps, caldera walls and glacial cirques (Fig. 12 ; Fig. 13). All of these landforms have steep slopes. Avalanche furrows rarely occur on slopes protected by many tall trees despite a large inclination and snow depth over 2 m. Poor vegetation and a dearth of tall trees is, thus, the third factor in FDSA occurrence and avalanche furrow formation.

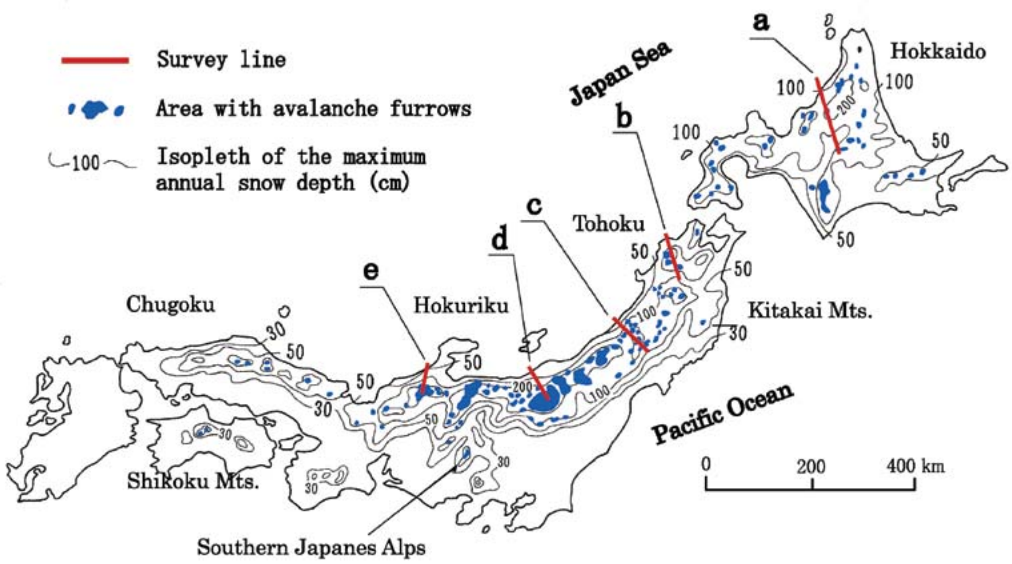

Fig. 10 Distribution of avalanche furrows in Japan. The isopleths of the maximum snow depth are drawn from the data of the Meteorological Agency.

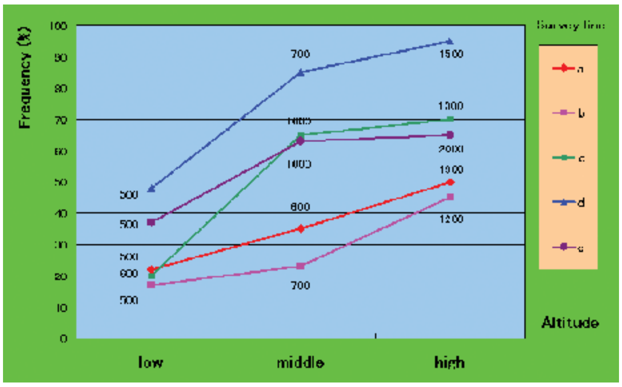

Fig. 11 Relationship between the occurrence of avalanche furrows and altitude. The survey lines are shown in Fig.10. a : Hokkaido, b : Northern Tohoku c : Southern Tohoku d : Eastern Hokuriku e : Western Hokuriku. The altitudes are classified into mountains of low, middle and high for each survey line. The representative altitudes (m) for the classes are indicated.

6.2 Comparison of snow avalanche landforms between Japan and other countries

The above mentioned factors affecting snow avalanches, i.e. heavy snowfall, steep slope and poor vegetation, seem to be common both in Japan and other countries. However, the altitudinal range for avalanche landforms is quite different. Avalanche furrows commonly occur in mountains as low as 300 m a.s.l. in Japan, which are located far below the timber line. In contrast, avalanche landforms in other countries occur mainly in polar and alpine areas with much colder climates (Shimizu & Abe, 2001).

The difference in the altitudes is considered to result from the unique Japanese climate that produces heavy snowfalls on low mountains and a rapid temperature rise in spring. With regard to the latter factor, the air temperature rises rapidly above 0°C in March, which promotes melting of snow and increases the water content at the base of snow, and eventually decreases the supporting power against snow avalanche formation, or decreases the drag coefficient at the base of snow (Endo, 1983). Thus, a large number of FDSAs flow down simultaneously on many slopes. It is concluded that the major factors for the formation of avalanche furrows in Japan are steep slope, poor vegetation, heavy snow and a warm climate in spring.

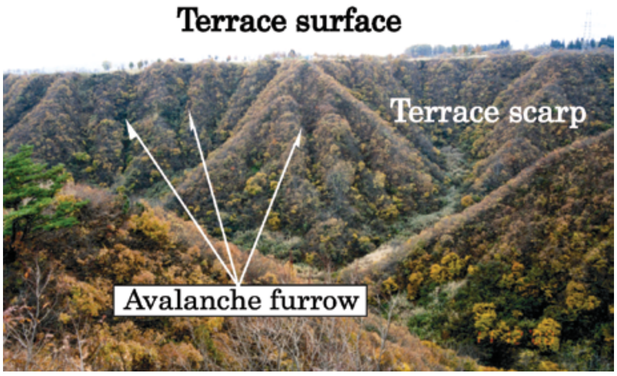

Fig. 12 View of avalanche furrows on river terrace scarp in Uonuma area (November 1985, by the authors).

Fig. 13 View of avalanche furrows on landslide scarp in Uonuma area (November 1985, by the authors).

Fig. 14 Avalanche patch on slope with full-depth snow avalanche in Toikanbetsu area, Hokkaido (October 1977, by the Geographical Survey Institute) .

Fig. 15 Ground surface of avalanche patch in Toikanbetsu area (September 2000, by Imanishi N., Hokkaido university).

6.3 Avalanche patches on full-depth snow avalanche slope

Slopes with FDSAs have avalanche patches in addition to avalanche chutes and avalanche furrows (Sekiguchi et al., 2003). Avalanche patches rarely exist in the upper and middle parts of the slopes with FDSAs. Figure 14 shows typical avalanche patches in Toikanbetsu area, Hokkaido. They are mostly elliptic shapes, with a width of several meters, a longitudinal length of 5-10 m and a depth of 10-30 cm (Fig. 15). On the inside of the patches are, in many cases, exposed soil and bedrock. The inclination of slopes with avalanche patches is gentler than those showing avalanche furrows, which suggests that the strength of the erosion by FDSAs is smaller in avalanche patches than avalanche furrows.

6.4 The effect of surface avalanche

Snow avalanches consist of surface avalanches as well as full-blown FDSAs. Surface avalanches usually occur from the surface of the snow pack, generally in heavy snowfall or snowstorm periods in severe winters. Though the surface avalanche seldom erodes the ground surface, it travels a long distance and causes considerable damage to houses and roads since it easily moves beyond obstacles such as forests (Saeki et al., 1975). Figure 16 and 17 show the example of "Maseguchi Surface Snow Avalanche Disaster", Nou Town, Niigata Prefecture occurred on January 26th, 1986. There are avalanche furrows and avalanche chutes on many slopes which have surface avalanches (Sekiguchi, 1993 ; Sekiguchi & Nishimura, 2003). As a result, it suggests that the surface avalanches and FDSA can occur on the same slopes.

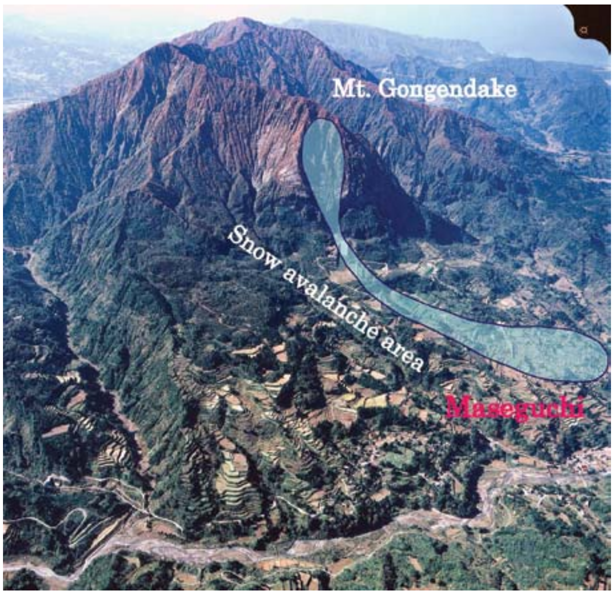

Fig. 16 Surface snow avalanche area caused by " Maseguchi Niigata Prefecture Snow Avalanche Disaster on January 21th, 1986" (October 1998, by Oris Co.).

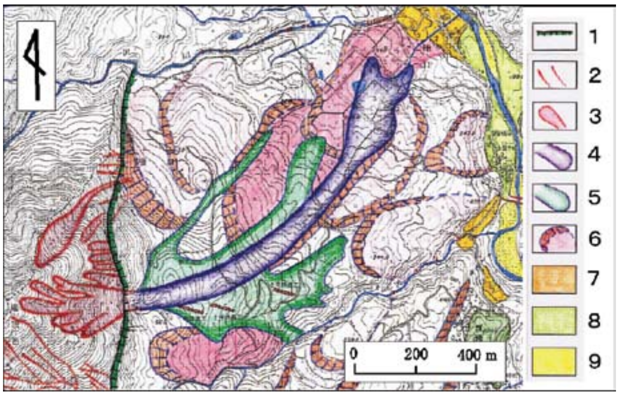

Fig. 17 Landform classification map of Maseguchi area (by Sekiguchi, 1991). 1 : Fault scarp 2 : Avalanche furrow 3 : Avalanche chute 4 : Main snow avalanche area by 1989 avalanche disaster 5 : Surrounding area by 1989 avalanche disaster area 6 : Landslide moved body and landslide main scarp 7 : Alluvial fan 8 : Flood and valley bottom plain 9 : Riverbed

6.5 Investigation of the snow avalanche landform using airbone laser scanning

Investigation of avalanche furrows and avalanche chutes formed by FDSA requires topographical maps of large scale due to their landforms. Recently, the preparation of the topographical maps of mountain slopes became possible using airbone laser scanning (Sekiguchi et al., 2004 ; Sato et al., 2004). Figure 18 shows an example of the avalanche furrows in Shirakami Mountains in Tohoku district superimposed on the laser contour map by airbone laser scanning (Sato et al., 2005). The airbone laser scanning technique can be effectively utilized in snow avalanche research because many avalanche furrows can be clearly recognized in the laser contour map.

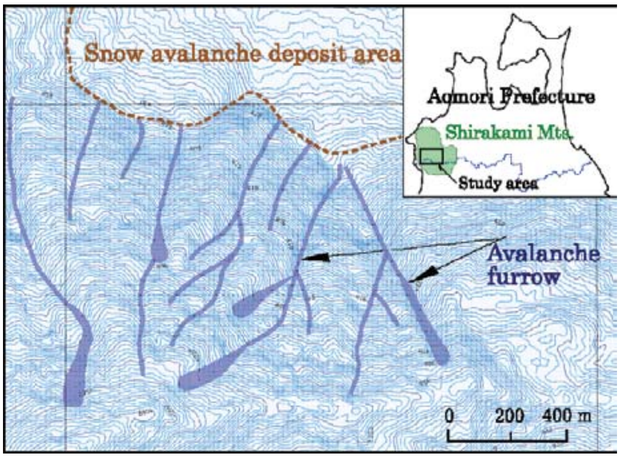

Fig. 18 Contour map using airbone laser scanning and avalanche furrows interpreted by contour map in Shirakami Mountains, Tohoku. Contour interval is 2 m.

7. Conclusions and perspective on snow avalanche research

Our investigations on geomorphological features and distribution of avalanche furrows in Japan lead us to the following conclusions.

Avalanche furrows are an important indicator of the occurrence of full-depth snow avalanches since they are seen on the slopes which have full-depth snow avalanches. Avalanche furrows show a semicircular or U-shaped transverse profile with a width of 2-4 m and a depth of 1-3 m, and develop mainly on mountain slopes with an inclination of 35°-45°. They have a straight longitudinal profile from near the ridge to the valley bottom. The distribution of avalanche furrows mostly corresponds to areas with a snow depth of over 2 m. Their frequency of occurrence increases with altitude. Avalanche furrows in Japan occur on slopes far lower than the similar landforms reported in other countries. In spite of much lower altitudes, steep slope, poor vegetation, heavy snow, and warm climate in spring may combine to cause full-depth snow avalanches repeatedly on the same slope, which eventually develop avalanche furrows.

Landforms formed by snow avalanche are

peculiar to the Japanese mountains facing the Japan Sea coast, and among the most representative landforms in Japan. However, research into these landforms with FDSA such as avalanche furrows and avalanche chutes is not progressing at present. In the future, it is expected that these landforms will be clarified in relationship to landform formation processes occurring in the Japanese mountains.

The Mid Niigata Prefecture Earthquake occurred on November 23rd, 2004, and caused a large number of simultaneously disasters such as slope failures, landslides, damming up many of the rivers. Roads and houses were also destroyed (Fig. 19). These regions are mountainous (300-400 m) and the prevelant geology is dominated by sand and Tertiary clay deposits. This has caused many landslides. The region has heavy snowfall reaching a snow-depth of 2-3 m every winter where many avalanche furrows are seen on the mountain sides and landslide scarps. Many slope failures and landslides caused by the Mid-Niigata Earthquake are steep slopes and unstable. Therefore, full-depth and surface snow avalanche occurrences are expected in those slopes (Fig. 20). We urgently need means for preventing disaster by snow avalanche and landslide.

Fig. 19 Landslide in Terano area caused by 2004 Mid Niigata Earthquake (November 2004 by authors)

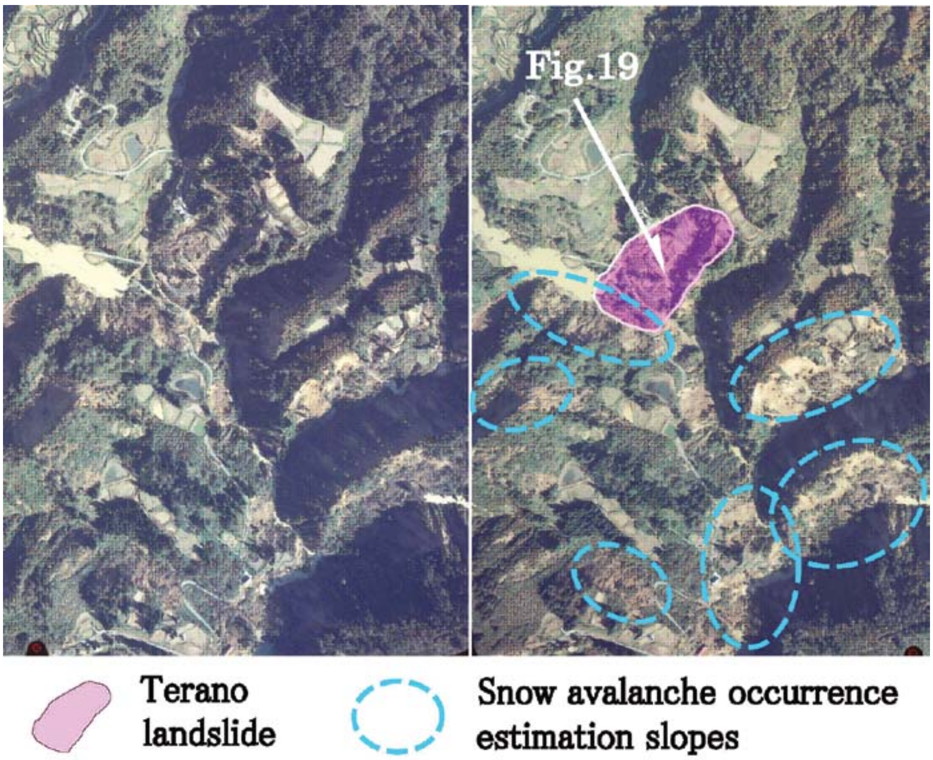

Fig. 20 Aerial photograph of The Mid Niigata prefecture Earthquake in 2004 in and around Terano landslide area (October 28rd 2004, by the Geographical Survey Institute). Possible use stereo vision with 3D.

References

Ackroide, P. (1986) : Debris transport by avalanche, Torlesse Range, New Zealand, Zeitscrift fur Geomorphologie, N. F. Bd. 30, 1-14.

Butler D.R. (1979) : Snow-avalanche Paths Terrain and Vegetation, Glacial National Park, Montana. Arct and Alpine Research. Vol. 11, 17-32.

Butler D.R., Malanson G. P. and Walsh S. J. (1992) : Snow-avalanche Paths : Conduits from the Periglacials-Alpine to the Subalpine-Depositional Zone. Periglacial Geomorphology. Edited by J.C. Dixon and A. D. Abrams, 185-202.

Endo Yasoichi. (1983) : Glide processes of a snow cover as a release mechanism of avalanche on a slope covered with bamboo bushes. Contributions from the Institute of Low Temperature Science, Hokkaido University, 32A, 39-68.

Gardener J. (1983) : Observations on erosion by wet snow avalanches Mount Rae area, Alberta, Canada. Arct and Alpine Research. Vol. 15, No. 2, 135-144.

Luckman, B. H. (1977) : The geomorphic activity of snow avalanche. Geogr. Ann., 59 A, 34-48.

Miyazaki Kenzo (1938) : The geomorphic considerations of snow avalanche. Geographical Review of Japan. 14, 731-744.

Onodera Hiromichi (1974) : Characteristics of snow deposit area in Shiretoko Peninsla, Hokkaido. Seppyo, 36, 21-23.

Rapp A. (1960) : Recent development of mountain slopes in Karkevage and surroundings, Nothern Scandinavia. Geogr. Ann., 42, 65-200.

Saeki Maso, Watanabe Shigeo and Ozeki Yoshio (1975) : Damage to Japanese Ceder Forest by Surface Avalanche. Seppyo, 37, 37-41.

Sato P. Hiroshi, Sekiguchi Tatsuo, Orio Kaoru and Nakajima Tamotsu (2004) : Accuracy Validation of Airborne Laser Scanning DTM Using the Ground Control Points. Journal of Japan Society of Photogrammetory and Remote Sensing, Vol. 43, 13-21.

Sato P. Hiroshi, Yagi Koji, Makita Hajime, Kato Satoru and Miyasaka Satoshi (2005) : Study on new vegetation mapping method using airborne lider data. Journal of the Japan Society of Photogrammetory and Remote Sensing, Vol. 44, No. 6, 36-39.

Sekiguchi Tatsuo (1991) : The comparison of geomorphological features by slopes where snow avalanche disaster occurrerd - For example Maseguchi avalanche, Sumon Village Okura avalanche and Kiyotu Gorge in Niigata Prefecture -. Preprints of 1991 Japanese Society of Snow and Ice.

Sekiguchi Tatsuo (1994) : Geomorphological features and distribution of slopes in heavy snow regions in Japan where full-depth avalanches occur. Seppyo, 56, 145-157.

Sekiguchi Tatsuo (2001) : The distribution of geomorphology caused by full-depth snow avalanche in Hokkaido. Preprints of 2001 Japanese Society of Snow and Ice.

Sekiguchi Tatsuo and Akiyama Kazuya (2002) : The distribution and features caused by full-depth snow avalanche in Tohoku. Preprints of 2002 Japanese Society of Snow and Ice.

Sekiguchi Tatsuo and Akiyama Kazuya (2003) : The distribution and features by full-depth snow avalanche in Kanto, Hokuriku and Chubu area. Preprints of 2003 Japanese Society of Snow and Ice.

Sekiguchi Tatsuo and Akiyama Kazuya (2004) : The distribution and features of full-depth snow avalanche in Western Hokuriku and West Japan areas. Preprints of 2004 Japanese Society of Snow and Ice.

Sekiguchi Tatsuo, Nishimura Koichi and Imanishi Nobuyuki (2003) : Slope characteristics formed by snow avalanche and patch morphology on the slope. Proceedings of the General Meeting of the Association of Japanese Geographers.

Sekiguchi Tatsuo and Nishimura Koichi (2003) : Snow avalanche disaster and geomorphological features in Niseko Annupri. Preprints of 2003 Japanese Society of Snow and Ice.

Sekiguchi Tatsuo and Sugiyama Masanori (2003) : Geomorphological features and distribution of avalanche furrows in heavy snowfall regions in Japan. Zeitschrift fur Geomorphologie, Supplement Volume 130, 117-128.

Shimizu Masujiro and Abe Osamu (2001) : Recent fluctuation of snow cover on mountainous areas in Japan. Annals of Glaciology, 32, 97-101.

Shimokawa Kazuo (1980) : Geomorphic study of avalanche chute in the upper drainage basin of the Tadami River. Geographical Review of Japan, 53, 171-188.

Sugiyama Masanori, Sekiguchi Tatsuo and Hoya Tadao (1987) : Research for solution between geomorphological factor and degree of snow avalanche occurrence. Geographic division research report, 50-59.