Report of the National Research Institute for Earth Science and Disaster Prevention, No. 66 ; September, 2004

Landslide Risk Evaluation and Mapping

- Manual of Aerial Photo Interpretation for Landslide Topography and Risk Management -

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Abstract

Landslide hazard prevention and mitigation is the important subject for national and environmental land management. The report introduce a way of landslide risk evaluation as an provability of reoccurrence of landslide action in the landslide topography. This evaluation is only for usage to the general observation. The target landslide topography for integrated field investigation will identify through this risk evaluation. The risk evaluation carried out by aerial photo interpretation and AHP(Analytic Hierarchy Process). The inspected landslide features will be marked on the inspection record sheet. The ideas of the risk is based on the hypothesis of autonomous destruction processes (Miyagi, 1991) and image of the changing process of the outline and interior landslide topography.

The check items for the sheet is selected 31 items and classified into 3 dimensions. The three dimensions are such as "landslide features in landslide body", "Aging features at the boundary of major landslide topography" and "Geomorphic setting of the landslide topography". The identifications and the level of contributions to the risk evaluations of each check items, which is constructed based on the photo interpretation and discussion by the high level landslide engineers.

Key words : Landslide, Risk evaluation, AHP, Photo interpretation, Inspection record sheet

1. Introduction

The understanding of landslide phenomenon from various viewpoints will be very useful to mitigate and prevent landslide hazard or to recognize the conditions of natural slopes. Landslide is a basic and significant ground disaster in various countries. A large number of landslide hazards such as tremendous economic loss, inconvenience by infrastructure destruction, even the human victims occurrence every year. It is needless to say how the evaluation of the landslide risk is important. By the recent advance of landform investigation through aerial photo interpretation in Japan and Nepal the huge number of landslide topography revealed. For example, the western half of Tohoku district where one third of sloping area is occupied by landslide topography. Landslide topography is never rare phenomenon in geomorphic/geologic process in these countries. However, the landslide topography and as the origin of landslide hazard is not equal. Landslide and landslide topography is different. The authors have to identify the actual meanings of landslide and landslide topography. The landslide topography is established by the activity of landslide. That has own geomorphic and geologic characteristics. Landslide topography itself has a higher potential of recurrence of slide action compared with the normal slope because the area is already destructed. Actually, all most of all landslide action happens at a part of the landslide topographic area. The risk evaluation is equal to the evaluation of the potential of reoccurrence. We have to evaluate the real risk of the landslide or identify the risky landslide topography. Even in the suspended or inactive landslide topography the original geologic character, particularly the strength of rocks is deformed. If we cut a part for road construction, the potential of landslide reoccurrence will increase. Some ration of the landslide topography has a high risk of the origin of the landslide hazard. We would like to try the identification of the risk evaluation by geomorphic approach as a first stage of risk management in this manual.

Recently, we often feel that the information about landforms should be used more effectively in making up hazard maps related with landslide management or prevention of landslide hazard. However, some engineers have very simple questions, such as "what and how is known by investigation of landslide topography."

Anyone can "see" a topography if it is defined as a mere surface form of the land. But, there are a lot of viewpoints in order to define it. Thus, this report will propose that it is a step toward into accurate understanding of the landform to establish a standard how to observe it. Before geomorphologists do their research, as preliminary steps, they probably interpret contour on the topographic map, interpret three dimensional aerial photographs and make a tentative landform classification map. When they identify the actual location of landform in the field by the topographic map, they will always take into consideration "what part am I seeing in this landform unit now?" That is, for geomorphologists, the field investigation is a place to confirm whether the landform classification map, which was formed based on topographic map and aerial photographs, is accurate or not. Thus, aerial photos should be brought along into the field and they are required to be observed closely, not looked at.

In this report, the following issues will be discussed; "how should we observe the landform and understand it", based on this understanding, "how high risk slopes, particularly landslide topography should be distinguished from other slopes of normal process" and "what can be known by classifying and understanding the characteristics of the slopes geomorphologically."

The photo interpretation is sometimes based on only their own experience and sense. This manual try to establish the inspection sheet in order to keep the inspector’s objectivity, reproductivity, which will be available for the data of field investigation.

2. Landforms: from various viewpoints

2.1 Topographic map, aerial photo, landform classification map

Tamura (1996) states the basic ideas about the recognition of a landform as follows. "As well as the views for all the components of nature, there are two viewpoints about landforms, that is, "continuous" and "unit". The former is an idea that landform should be regarded as a ‘continuous’ one, and the latter is an idea that it should be captured in terms of ‘units’." It is not until we stand in the latter option that the work of land classification will be implemented well.

What is "continuous"? It is a perspective that regards the landform as a piece of cloth which closely covers the earth surface. Based on this idea, it will be possible to express a landform surface by contours. The representation by contours will enable us to capture objectively the geomorphologic properties of various shapes, for example, a slope’s inclination, curvature, direction, position, and ups and downs, etc. with a certain accuracy.

Fig.2.1, a contour map with the special geomorphologic characteristics given by the DEM (Digital Elevation Model) data 20m grid, shows river terraces of the Hirose River, which lies in the west of Sendai, northeast Japan. This figure illustrates that A is a junction of the River Okura and the River Hirose and that both rivers steeply dissect the flat of terrace B over 40-60 meters in relative height. The surface of river terraces of C, D, E and F distribute above the terrace surface B. The inclination of river terraces except B and C can be measured by space of contours. The gradient of river floor and stream direction of each terrace can be measured, too. It is possible to capture the relative height between the river terrace surfaces to some extent by countering the number of contours that consist of the surface of cliff. However, it is a little difficult to identify where

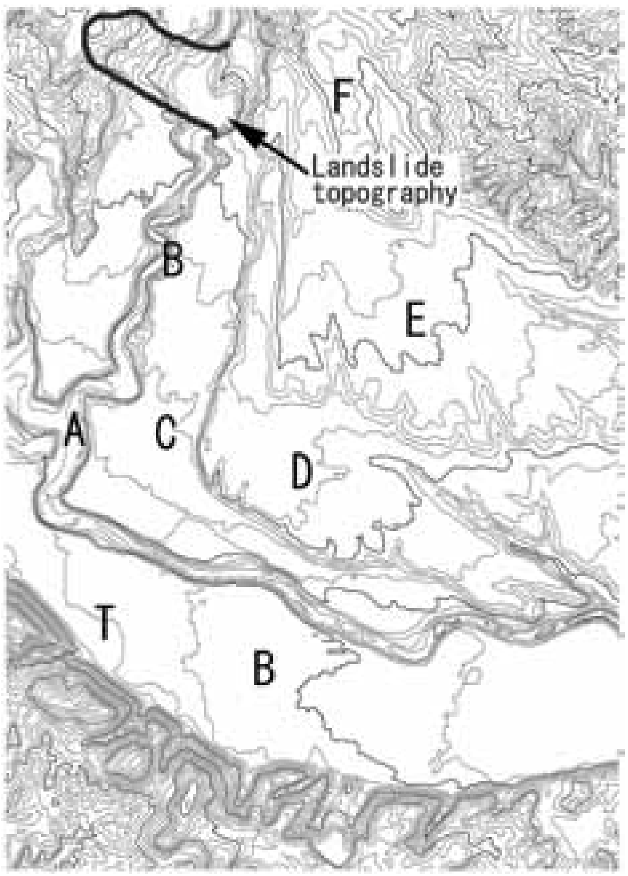


Fig. 2.1 Contour map of the Hirose River and terrace topography. Contour lines are described based on the 20 meters grid DEM data. Small landslide topography appears as the systematic winding contour.

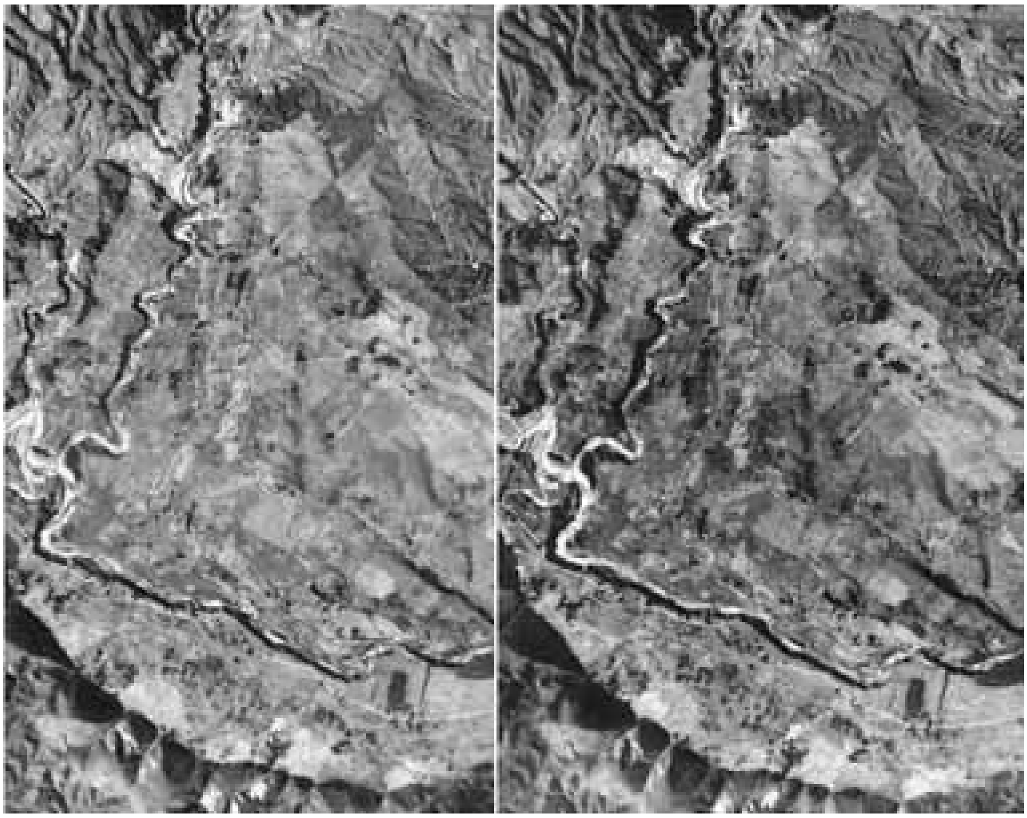


Fig. 2.2 Stereo pair aerial photographs at the same place of small landslide topography and small altitude terrace cliff is relatively easy to identify.

terrace cliffs B and C is formed, since the relative height of them is too small in the contour interval. **Fig.2.2**, which is an aerial photo covers almost the same range, is paired to identify in three-dimensional way using a stereo pair aerial photograph. These pictures show clearly the geomorphologic characteristics of the landform provided by contours, and a continuation of small river cliffs below the position described as C in the contour map. The relative height of these small cliffs is about less than 10 meters in vertical at some point.

At the lower part of these aerial photos, there are hill topography, steep hill slopes and a lot of alluvial cones. The position of the clearest one among those is represented as T in the contour map. Notice that when observing the curve of contour, it becomes clear that at T, two contours, taking a form like a fan, curve toward the northeast. Thus, it seems that exact contour lines can capture the characteristics of landform to a still good extent.

Now, what is the landform classification map? **Fig.2.3** is a landform classification map covers almost the same range. This is formally called a "river terrace surface classification map." In this map, in addition to river terrace surfaces of 5 surfaces, alluvial corn and landslide topography are illustrated. But other types of landforms are lumped together and their characteristics are only skimmed. This illustrates the distribution and geomorphic development of river terraces interpreted through aerial photographs and field inspection. This figure is quite different from any other aerial photos or contour maps in that it interprets and illustrates the results of the observation discussed above. That is, the inspection of contour maps and interpretation of aerial photographs seem to make possible to form a river terrace surface classification map and understand the characteristics of river terraces in this area. The landform classification is to find some significant landform units (which will be discussed in later chapter), here river terraces, and to illustrate its condition as a "special arrangement of the typology of the landform."

2.2 Geomorphic setting four kinds of viewpoints

A landform which is recognized as a unit contains four features; Form, Material, Process and Age. The landform is defined and classified in these terms. As the research proceeds, the definition of each feature has been gradually established. Among these features, Form and Material basically intend some visible features. Process and Age are the features that are investigated by analyzing the two former features (Tamura 1996).

Fig.2.4 shows these four features, taking river terraces of a part of the Yoneshiro River as an example. From this point of view, each feature is explained as follows. Form; Form of a river terrace is the combination of platy topography called river terrace surface and the cliff called

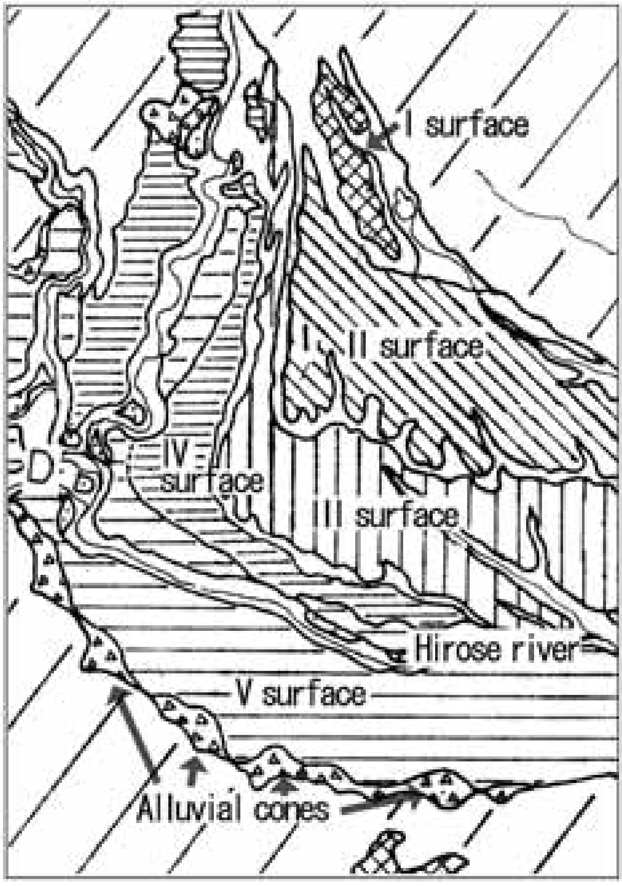


Fig. 2.3 Landform classification map of Hirose River (Ohuch, 1973), which is described by photo interpretation and field study.

terrace cliff. Here one combination is displayed. Material; Material is the sediment that makes up the river terrace surfaces. Material has various characteristics, which are usually recognized through detailed field investigation. This figure shows that there are three kinds of Material (namely, the sediment) in the frame made up of bad rocks. That is, terrace deposit 1 is a thick deposit that fills a valley as thick as more than 10 meters. Terrace deposit 2 consists of rounded gravel, which lies thinly just under the river terrace surface 2. The terrace deposit 3 is thin rounded gravel that covers the terrace deposit 1 and cut a part of terrace deposit 2. The volcanic ash covers terrace surface 2 and it was cut by development of terrace 3 surface. Material of the river terrace 1 seems to be thick fluvial sediment that had been deposited in a certain period long before the terrace surface 2 was formed. But it is impossible to identify the terrace surface of this deposit because it had been deformed by some geomorphic development in the later period. Process; as mentioned in connection with the two former features, the then river eroded the lateral of the aged terrace deposit which was made up of the terrace surface deposit. After that, it had been depended, finally forming the terrace surface 2 and 3. In this case, it can be said that the terrace surface 1 was formed by fill up the river floor, 2 and 3 surfaces were formed by lateral erosion of the river. Age; by radio carbon dating of the volcanic deposit that covers the surface of terrace 2, it is possible to conclude that Age of the terrace surface 2 had been formed in a period before about 12000y.BP. The methodology of tephrochlonology is also very common to

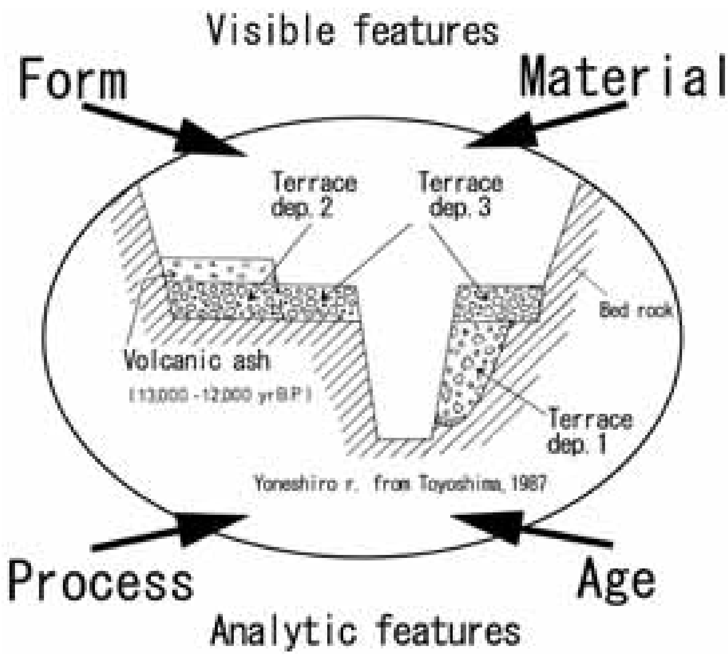


Fig. 2.4 Four kinds of features of Landform identification.
Form will be identified by photo interpretation and all other features are neglected.

identify the age of geomorphic surfaces.

From the above discussion, landforms will be understood in terms of geomorphology. Thus, if we observe a mass movement of slopes and various kinds of landforms, it will be necessary to consider several problems, such as "what form does this slope take," "what material constitutes this slope," "how was this slope formed," or "when this slope was formed." The understanding of these things will be useful to prevent landslide hazards.

3. Landslide hazard in Nepal, Thailand and Northern Japan

3.1 Landslide types in physiographic regions of Nepal

3.1.1 Geomorphic and geologic features of Nepal

Nepal is an independent kingdom located between China on the north and India on the south and on the Mid Himalayan Mountain Section of Asia. It is small landlocked country situated at the distance 500km from the nearest sea. It stretches for 885km from east-west and about for 193km north-south. The total area of the country is, 147,181 Square Kilometer.

Nepal is mountainous country about 83 percent of the total area is covered by the mountains and 17 percent is covered by Terai plain area. The landforms of Mountains, Hills, Inner valleys and Terai plains are characterized by fragile geology, steep slopes having faults and folds and the environment of high relief energy which is dominated by ancient and present mass movements. It is geomorphologically divided into five zones which are bounded by big thrusts. The Terai zone lies in the southernmost part of the country at about 70 to 200m a. s. l. and it is an active foreland basin consisting of alluvium with different grades of sediments. The Siwalik Hills lie between the Main Boundary Thrust in north and the Frontal Thrust in south and rise about 200 to 1,300m a. s. l. The hills are composed of northward dipping lower Quaternary and Tertiary sedimentary rocks like sandstone, mudstone, marl and conglomerate, which are characteristically soft and loose. The Middle Mountains lie between the Main Boundary Thrust in south and the Main Central Thrust in north and rise about 1,300 to 3,000m a. s. l. The Middle Mountains are chiefly composed of lower to higher grades of metamorphic rocks like slate, phyllite, schist and quartzite, associated with granites, limestone and dolomite of different ages, which are characteristically deep weathered and highly fractured with several major and minor local thrusts and faults. The High Mountains, which lie in north of the Main Central Thrust about 3,000 to 6,000m a. s. l., are composed of highly metamorphosed phyllite, schist, gneisse, and quartzite. They are characteristically more resistant to weathering, whereas the upper phyllite layer is highly weathered in nature. The High Himalayas rising 7,000 to 8,000m a. s. l. have gneiss, schist, limestone and shale of different ages (Sharma 1990, Upreti 2001). The precipitation variation in the country ranges from less than 300mm in the dry region to more than 5,000mm in the wet region. Nearly 70 to 80 percent of the total rainfall occurs within 4 month from June to September and the mean annual precipitation is almost 1,530mm.

3.1.2 Landslide types in physiographic region

Nepal has more than 6,000 numbers of rivers and rivulets that have distributed lands into several watersheds. Several large and small rivers, which originate from the High Himalayas, the High Mountain and Middle Mountains zones and flow to Terai, consist of several numbers of watersheds.

The watersheds of the High Mountains have powerful and torrential storm and great snow and ice avalanches. Their slopes are deeply eroded by undercutting of glaciers and river action. The types of landslides in the High Mountain regions, eroded of rock, rock fall, rock creep avalanches are common. The watersheds of the middle and lower mountains ranges, rock fall at the tops, talus creep large deep-seated landslides and surface slides in the middle and soil creep, gullies, slip slides deep and slump at the base are common. The different types of mass movement in the Middle Mountains are predominated caused by natural processes like earthquake, high rainfall intensity and human interference such deforestation, agricultures, residents, road, and irrigation channel constriction on steep slopes as well as combined of them.

The landslide dynamics and specific morphometric condition created four different types of sliding surfaces in chronological sequence in the Himalayan mountain region. The primary sliding plane occurs on the basement, where fractures and narrow trenches were formed and the secondary sliding plane occurs in parallel to the primary ones. The Tertiary sliding plane comes vertical to the basement and sub-parallel to the slopes (John *et al.*, 1998).The quarterly sliding planes are the causes of local events. Among them, deep-seated landslides are frequently found along tectonic lines and weak geological composition, whereas surface slides and small deep-seated landslides are remarkable on the both gentle slope and steep slopes and are induced by not only heavy rain and earthquake but also land encroachment for agriculture, deforestation, stone quarrying and road construction. Most of watersheds in the Middle Mountains and the Siwalik Hills, where densely population concentrated, are highly susceptible to mass movements' surface slide and different scale of deep-seated landslides, which have potential to bring heavy disaster not only in the sliding site but also in the watershed extending to Terai (**Fig.3.1**).

The general trend of mass movements on the Himalayan Mountains has been classified on the basis of altitude. The earth flow/mud flow occurs on the Siwalik Hills and the

Middle Mountains. The debris flow occurs on the Middle Mountain, the High Mountain region and lower part of the Himalayas and the ice avalanches occur on the High Mountains and the Himalayan zones. The ice avalanches and rock slide/rock fall flow quickly undercut slopes and generate much of the surface failures. Generally the torrent and storms generate the landslide and debris flows that undercut the valleys and divert the river flows to both sides of the riverbanks. They create additional more or less independent events. It can be sometimes noted that debris flow and rock fall /rockslides dam up of the narrow river valleys. Consequent burst out of the dam brings about great disasters in the mountainous region and rise of the riverbed in the Terai Foreland Basin. Thus the surface slides and deep-seated landslides by heavy rains bring heavy disaster in the watershed and people are suffering from several types of water induced disasters like landslide debris flow and flooding in every monsoon. These processes have drastically changed the landform environment in the mountainous watersheds and Terai.

The recent example is that several large and small landslides and surface slides by heavy rain produced a big disaster in different watersheds on the middle and eastern mountains and Terai in 1993. The disaster destroyed 43,330 hectares of lands, 452 numbers of buildings, 3,667km of roads, 313 numbers of bridges, 34 numbers of dams and 626 numbers of irrigation channels including Tribhuwan and Prithibi highways, Bagmati barrage and Kulekhani hydropower station with about 1,500 casualties (Report of JDR Team, 1994; Water Induced Disaster Prevention Technical Center and Central Department of Geology Tribhuvan Univ., 1994). The debris flow induced by these landslides destroyed forest and agriculture land (terrace and paddy field) on hillslopes in the Middle Mountains, Siwalik and Terai (Yagi and Oi, 1993; Tamura, 1996; Tamura and Gyawali, 1996), which have brought about degradation of the watershed environment. Some photograph of slope failures and deep seated landslides in the middle mountains and Siwalik Hills which were taken is different periods of monsoons in Nepal have been demonstrated.

Fig.3.2 and **Fig.3.3** shows the Chisapani landslide which is located in the uppermost watershed of the Agra khola in the Makwanpur district of Nepal is the example of the old landslide in the middle mountain which reactivated in July 1993. This landslide killed 4 people and damaged 32 houses in the Chisapani village and debris flow and flood damaged the Prithivi high way at downstream. Although some people have already migrated from the landslide areas to other safe places like Hetauda and Terai, however most of the people are still living on the vulnerable area of the landslide. According to the version of local people in the landslide area, this landslide reactivated in 1993, 1954, 1970

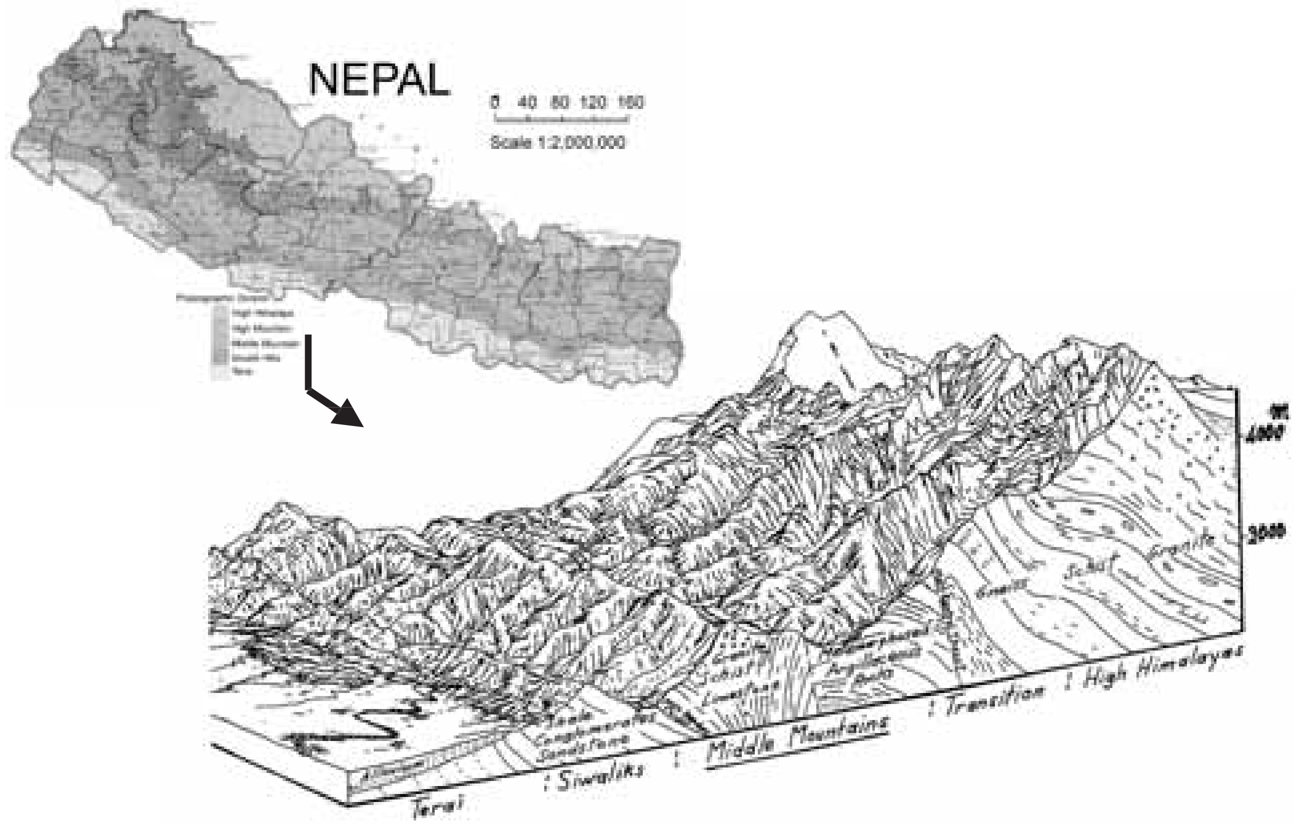


Fig. 3.1 The geomorphic zone of Nepal (Nelson *et al*., 1980).

Fig. 3.2 A view of Chisapani landslide at the uppermost Agrakhola watershed in the Central Middle Mountain range of Nepal. This is a very old landslide which reactivated in 1993 disaster and is still in active condition. Several cracks are developing on the head of the landslide, several active gullies are developing in landslide body and the new scarps are extending upward collapsing the unstable blocks of landslide (Photo view is from east to west).

Fig. 3.3 A view of Chisapani landslide at the uppermost Agrakhola watershed in the Central Middle Mountain range of Nepal. This landslide is very old and is still in active condition. (Photo view is from west to east).

Fig. 3.4 A view of surface landslide on the degraded Hillslopes at the uppermost of Kulekhani watershed in Central Middle Mountain of Nepal.

(Before Disaster)

(After Disaster)

Fig. 3.5 A view of Namtar Bazar (left) before and (right) after the disaster in July 1993 at the upper watershed of the Monohari River at the range of Middle Mountain and Siwalik Hills of Nepal.

Fig. 3.6 An over view of Jogimara landslide which damaged the Prithivi Highway (Muglin to Kathmandu road) in the Middle Mountain of Nepal. This photo was taken just after disaster in July 1993.

and 1993. However no any recorded evidences has been found of reactivation of landslide in the past. Several old and recent scarps and linear tension cracks are clearly defined in the head and the landslide body which indicates that these landslides are still in active condition. All the agriculture lands (Bari and Khet) in the landslide area have been still using which is very high risk for the future reactivation.

Several slope failures on the northern slope of the middle mountain which is located in the Palung village development committee, uppermost Kulekhani watershed Makawanpur district Nepal occurred due to heavy rainfall in July 1993 (**Fig.3.4**). The rainfall was recorded 540mm in 24 hrs in 20 July1993. Similarly Namtar Bajar at the foothill upstream of the Manohari khola in Makwanpur District was washed way by accumulated debris flow and flood of Dhungakate khola and Ghatte khola. Several landslide, rockslide and gullies occurred in the upstream catchments area of Dhungakate khola and Ghatte khola due to same high rainfall intensity. The **Fig.3.5** shows Namtar Bazaar before and an after disaster. Tribhuban and Prithivi highways which are linkage road to Kathmandu, the capital of Nepal were damaged by several landslides. **Fig.3.6** shows the Jogimara landslide in the Prithivi highway. In addition, the foot trails in the middle mountainous regions also created big problems of water induced disaster in Nepal as shown in **Fig.3.7**. The foot trails are converted into gullies by the erosion due to runoff water and in which accumulated run off water scoured made deep gullies during the rainy season and concentrated of runoff initiated to rigger the landslide at the lower convex breaks of the Hill slopes.

Several landslides on the southern slopes of Siwalik Hills have also created serious problems in Nepal. Sharwan danda landslide **Fig.3.8** is the example of Siwalik hills which is located in the southern slope of the Siwalik hills in Butwal occurred on August 12, 1998, and a huge amount of debris flow damaged 37 houses, and partly affected 66 houses, killed 1 person and injured 5 persons at Jyotingr while heavy rainfall was recorded 155.3mm on 11 August 1998. The damaged property of landslide was estimated about NRs.58millions. This is also old landslide reactivated at presently (Gyawali, 2003). This landslide is composed of young sedimentary rocks (sandstone, shale, mudstone and conglomerate) of the Lower Siwalik Formation which overlies crushed loose colluvial of the Quaternary deposits, lies just behind the Main Frontal Thrust (MFT) (Sharma, 1990). The unstable masses are still partly moving and the debris flow is affecting public houses, foot tracks and roads at Jyotingr and Laxminagar in Butwal. This landslide is very high risk to the people of Jyotinagr and Laxminagar where more than 10,000 people are living.

3.1.3 Conclusion

Hence several ancient landslides in the middle mountainous and Siwalik Hills in Nepal are used for the agricultural and settlements purposes (Upreti B. N., 2001 and Tamura T. 1996) are difficult to recognize as simple field inspection by the people. Population growth and their existing pressure unknowingly disturbed the hillslope surfaces or surface drainages of slopes, materials, and structures may destabilize them. In addition high rainfall initiates to erosion gulling, undercutting river and landslides, debris flow and flooding during monsoon.

Thus denudation and mass movements in the upstream mountainous watersheds supply debris which moves progressively downstream to destroy lands, properties and people in the plains. At the same time, the events were recorded on the landform and deposits in the watershed.

The interpretation of chronological sequences of geomorphic development and variable sources of debris and sediments are essential for understanding the characters and timing of environmental change in the watershed. Hazard mapping to find out the landslide potential landform to landslide and their risk evaluation of such types of ancient landslides through the aerial photo interpretation and field verification will greatly help to hazard reduction and make aware the people who are living in the vulnerable area.

3.2 Landslide hazard in Thailand

3.2.1 Introduction

From the records of past few decades, landslide occurs frequently on the slopping of Thailand, especially in areas where rainfall is relatively high and natural forest was devastated. On nearly every occurrence enormous natural resources as well as human properties, households and even life, were demolished. Moreover, the climatic change causes erratic rainfall and agricultural land use on slopping areas affect the increase of the forest devastation. This occurrence tends to increase year by years.

At the end of rainy season in 1988, the huge tragedy happened at the Phipun area, Nakorn Si Thammarat province southern Thailand by landslide disaster. In recently, unanticipated landslide and flood hit a small village in Pechabun province, central highland in Thailand 2001. The government realized about the necessity to set up the measure to prevent and/or mitigate the occurrence and disasters in Thailand. As a consequence, they set up the national committee to consider and/or conduct such measures. Considering by the committee, the activities that should be included in the measure are to map the actual and potential landslide area of the country and to create and conduct the measure to prevent and/or mitigate the occurrence. Thus the agency academic groups in university responds to take care the land resources of the country. Land Development Department (LDD) was assigned to conduct this mapping activity as well as to create and conduct the measures to prevent and/or mitigate such disaster occurrence.

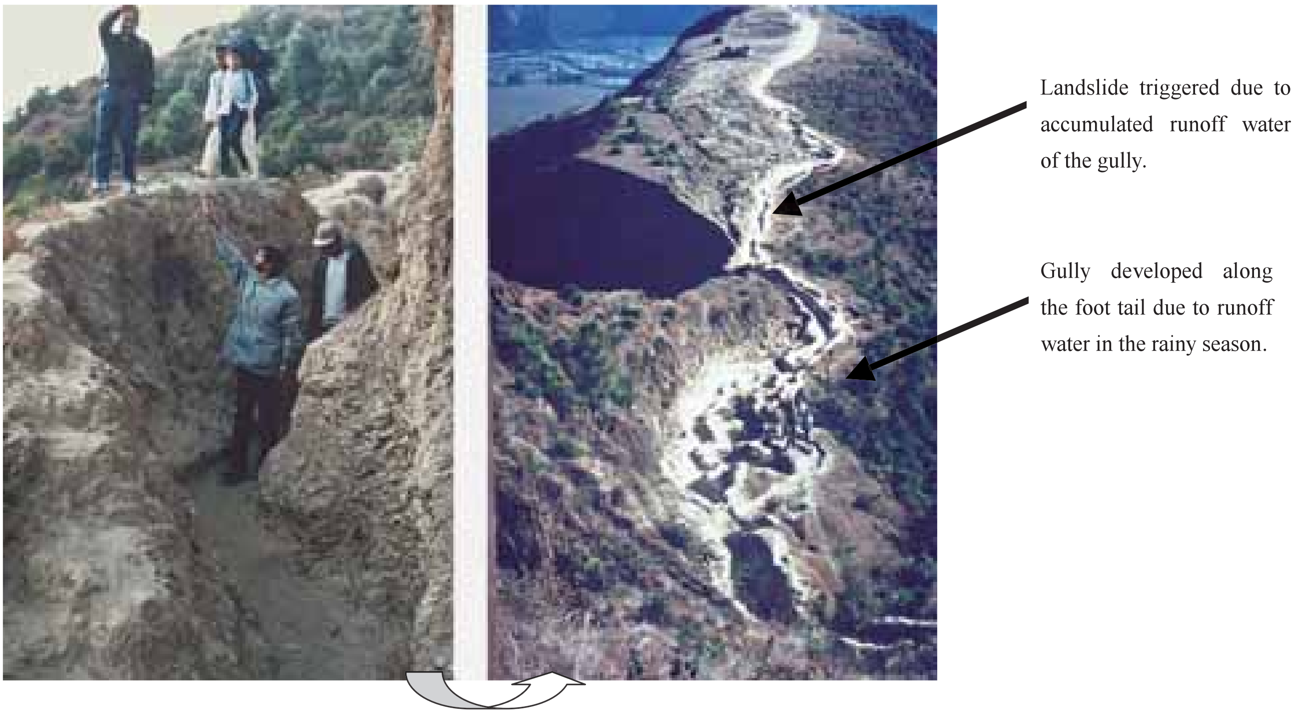


Fig. 3.7 A view of foot trail at the Middle Mountain of Nepal, this foot trail changed to a gully and at the end the gully changed to a landslide due to accumulate surface runoff during the monsoon.

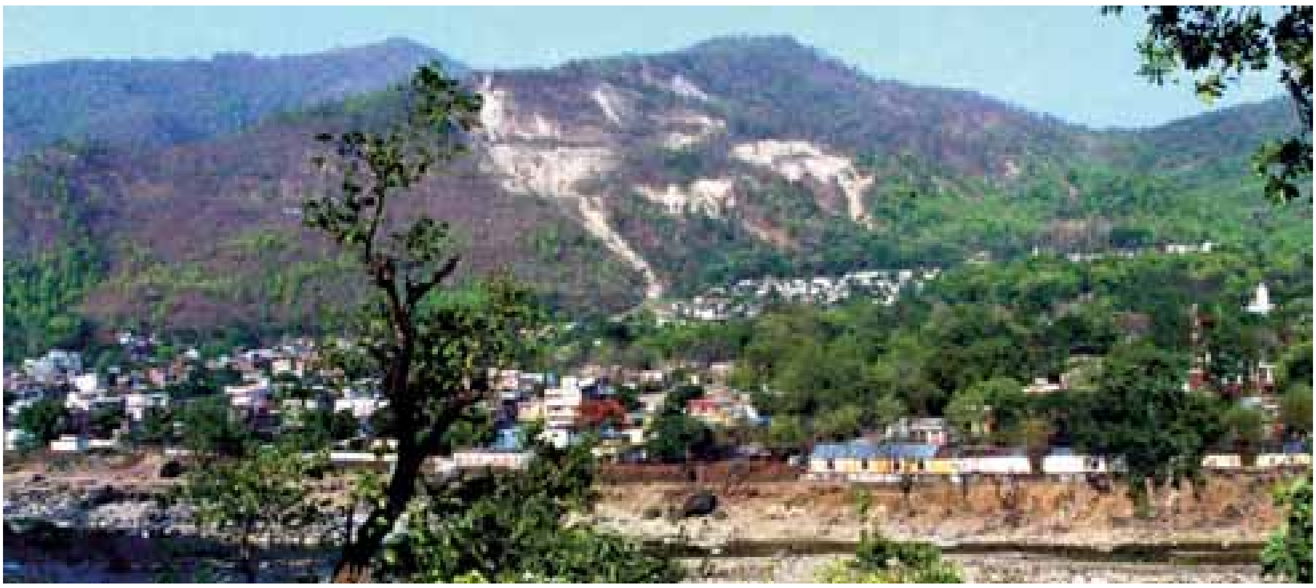


Fig. 3.8 An over view of the Shrawan danda landslide on southern slope of the Siwalik Hills in Butwal Rupandehi District Nepal. (This landslide occurred in August 1998).

Now, LDD and Japan Landslide Society promote the collaborative mapping project titled "Landslide Mapping and Risk Mitigation Planning in Thailand" by submission of the International Consortium of Landslide (ICL) project. Here, we would like to introduce the outline of the project as follows; The object is; "Map the actual and potential landslides in Thailand in regions that are planned for development or that have been developed, and design and conduct prevention and/or mitigation measures". The major project activities are as follows:

(1) Determination of the priority mapping areas in Thailand by considering the physical, social and economic conditions within the country.

(2) Mapping the actual and potential landslide regions in the designated priority areas.

(3) Conduct of research on the improvement of landslide evaluation methods, technologies and/or measures to prevent and mitigate the disasters.

(4) Technology transfer and exchange of information on landslide mapping, prevention and mitigation technology. The primary target is the National office of LDD, Thailand.

(5) Formulation of a strategy of landslide control for particular priority areas.

3.2.2 Some information of landslide hazard and the potential

(1) Phipun in Nakorn Si Thammarat province (Fig. 3.9 a,b,c)

In November 1988, near the end of the rainy season when rivers and soil were already saturated, an intense five days storm poured and additional meter of rainfall in some area, and the people of Southern Thailand were struck by widespread floods and landslides. Over 370 lives were lost. Relief and repair efforts by the government, NGOs, and international agencies quickly amounted to over ($170 million). Total economic damages are estimated to have $300 Million. The disaster centered on Phipun area, where 175 people perished. Logs and landslides swept down from the mountainsides surrounding the Phipun basin to destroy more than 900 homes, and bury more than 10 percent of the valley's ricefields and fruit orchards with sediments and rocks (after National Economic and Social Development Board (NESDB), 1991). The most of the landslides occur at the surface soil layers and are come from deeply weathered granitic rock. The huge amounts of the earth flow material transported in three times and buried the valley bottom, which caused the loss of victims.

(2) Pechabun province (Fig.3.10 a,b,c)

In November, 2001, strong flash flood hit and 136 victims in two small villages near Lomsak City, Pechabun province. There was no rainfall at the villages when the flash comes. Villagers believed the heavy rainfall came in the upper reach of the drainage area. But there is no meteorological measure station around the area. The flash flood supplied a huge amount of sandy materials and logs except rocks. LDD clarified the huge number of scars occurred at the hillside slope surrounding the upper reaches. Each scar is very small and thin (usually less than 1ha. and less than 0.5meter thick). However, the total amount of the sediments seems to be not enough for the damage. We suspect the formation of the landslide dam somewhere of the gorge. On the other hand, almost of all the scars occurred at the glass land after the burning for shifting cultivation. The land degradation can be considered as another trigger of landslides.

(3) Chiang Mai area (Fig.3.11 a,b)

The relatively high mountain region such as Chiang Mai and Chiang Rai province received heavy rainfall in June to August 2003, and a great number of surface landslides occurred at the road side cuttings and deeply weathered slopes. Some of the small surface landslides are a kind of the risky feature of large scale landslide. For example, small surface landslides at Ahnkhan district may indicate such feature.

Rapid flow type landslide occurred at hill slope near Chiang Mai. The landslide destroyed a gentle hill slope which consists of deeply weathered andesitic rocks. The square of destroyed area reaches about 50m by 100m in the area and main scarp is 10 meters high. The landslide body was quickly transported to the river floor in lower reaches. This material transported about 300meters and thinly deposited, it established a wide flat plain. The trigger of the rapid flow type landslide seems to be the large amount of water infiltrate to the weathering body.

3.2.3 Conclusion

The landslide hazards are getting common year by year. The surface landslide was caused by heavy rainfall to the degraded slope and at the same time the large scale landslide will be clarified by our study. The deeply weathered materials and geologically reworked material such as colluviums are easily observable in the mountain side. Large scale and various types of landslide topographies can be identified by photo interpretation (**Fig.3.12**).

3.3 Northeastern Japan

3.3.1 Introduction

Japan islands are located in eastern margin of Asia continent and are located in humid temperate climate zone. The location leads heavy rainfall in summer and much snowfall in winter. The chain islands, especially northeastern Japan main island, has typical characteristics of arc and trench system. The system as a part of the Circum Pacific Orogenesis zone has the high activities of volcanism, crustal movement and earthquake, etc. Thus the geology is relatively young (mainly consists of Neogene sedimentary rocks and Quaternary volcanics) and the slope has steep gradient. Chemical weathering process, dissection and deposition

Fig. 3.9 Landslide disaster at Phipun basin on the western hilly part of Nhkorn Si Thammarat province Thailand. a; an overview of surface landslides and debris. b; flood and sediment buried a village. c; slopping area is covered by rubber plantation. The rubber trees can not grasp the soil because of the shallow root system.

by fluvial process are also very active. Landslide is very common because of such environmental characteristics.

According with the increase of human activities recently, artificial land deformation by civil engineering work in sloping area that has been widely developed in and around urbanized area. Such human activity is not only at residential area development but also at golf field, industrial area, airport and paddy field development. We have to pay attention to such artificial landform. The artificial land deformation is the process of cut the higher portion and fill up the valley for develop the platy ground. The valley fill area is slightly weak compared with the cut portion for earthquake wave. The soil strength of some valley fill material area is getting reduced with aging. The ground water condition will also change. Thus the potential of landslide in artificial valley fill area is higher in some case.

The authors like to introduce some cases of recent typical landslide disasters in Tohoku district.

Fig. 3.10 Landslide hazard hit two small villages where located by the river at the mountain margin of Lomsak basin, central Thailand. a; A great number of erosion landslides (scars) occurred at the poor land cover watershed. b; Flash flood washed away houses and lives. c; The debris only consist of fine materials and logs.

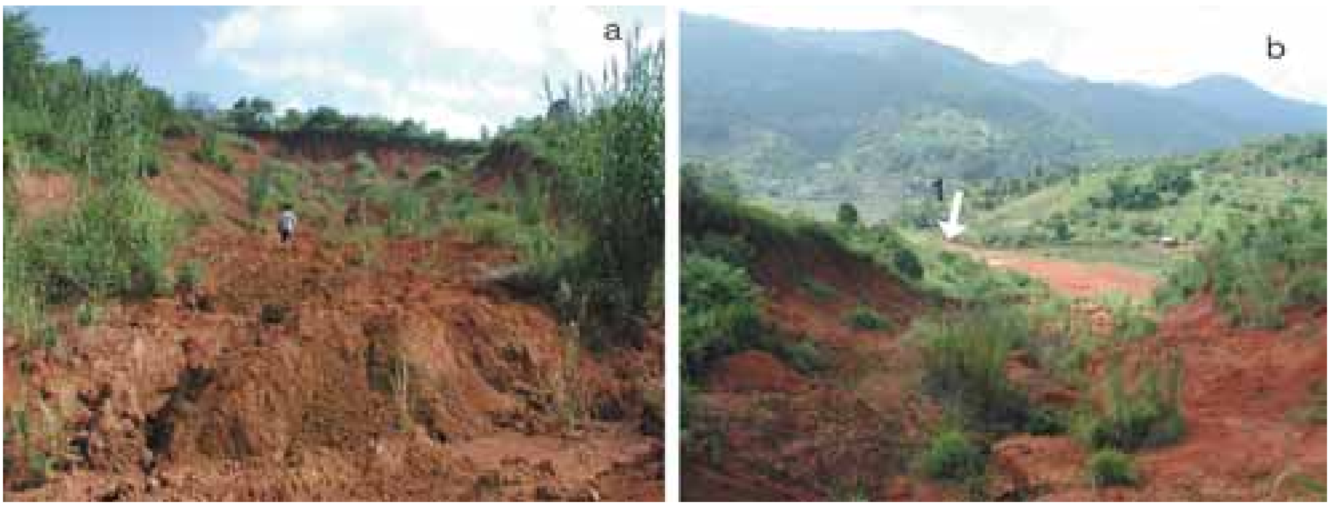


Fig. 3.11 Rapid flow type landslide at the foot slope near Chiangmai City northern Thailand. a; The source area is located at the gentle hill foot slope which consist of deeply weathered andesite. b; The slip surface has gentle gradient and the body run and scattered long distance (white arrow is the portion of toe).

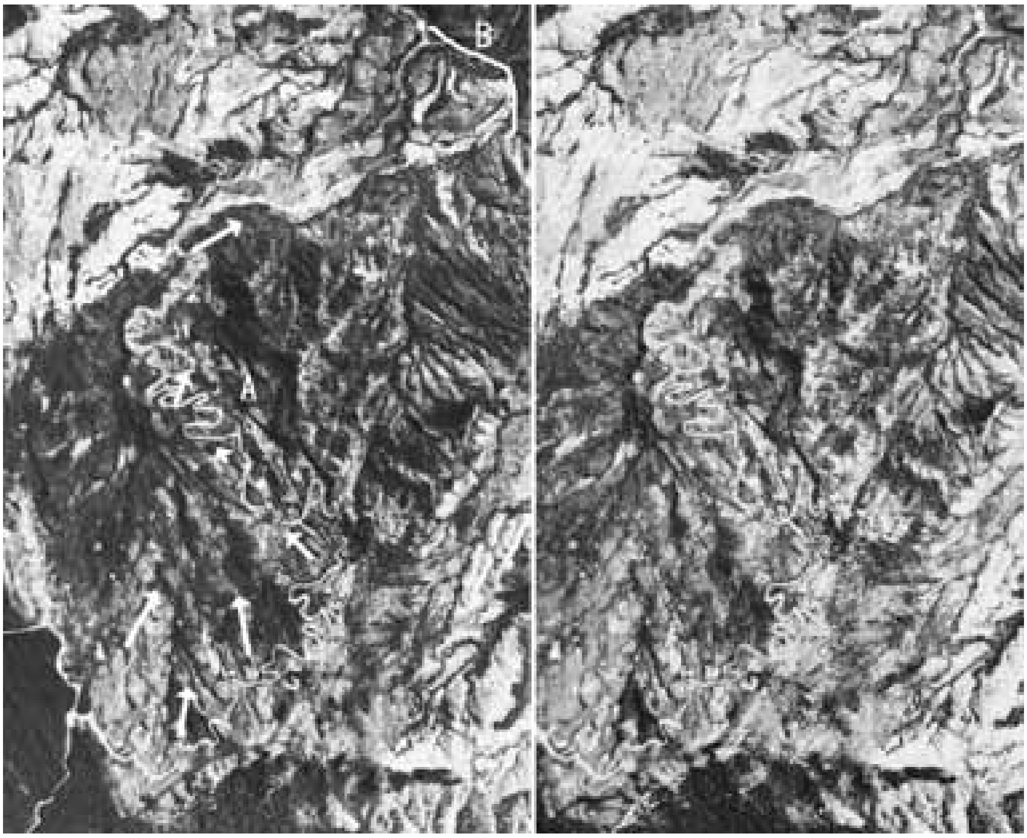


Fig. 3.12 A stereo pair aerial photographs at a part of central Thailand. (A number of arrows show the similar to slump to debris flow type landslide topography and a part of debris flow leached at the B).

3.3.2 Introduction of landslide hazards

(1) Large scale landslide

Fig.3.13 shows the over view of landslide topography. The Sabuta landslide in Yamagata Prefecture was marked as a large scale landslide topography. There are many scarps in shape of horse shoe and many small cracks in the behind. It is easy to recognize a typical landslide topography from the geomorphic point of view. But, no direct landform deformation has occurred last several decades. So there were several opinions of the risk of reoccurrence of landslide hazard. At the spring 1998, the toe part collapsed to the river and the road at the part of crown subsided gradually. The action restarted by the area of 600m in width and 1,100m in length. The velocity of the surface movement reaches to several meters par year. The surface of rapture revealed at the depth of 70m by borings. Actually a part of the area deformed and slipped down into the river about 50 years ago. 38 lives had lost at that action.

(2) Large scale landslide and debris flow

A landslide occurred at Sumikawa hot-spring site, Akita Prefecture on May 11, 1997 (**Fig.3.14**). The landslide destroyed 9 houses of the hot spring area and the debris avalanche down 2km along the river. The landslide area was mentioned at the landslide classification map (**Fig.5.13**, Shimizu *et al*, 1984, 1/50,000 in scale).

The surface of rapture can be found along the ancient valley between the landslide body which was composed of anesite lava flow deposit and underlying formation of the early Pleistocene caldera silt and pyrocrastic deposits.

(3) Rapid flow

Northeast Japan received a huge amount of rainfall by the combination of low pressure and typhoon during August 26~31, 1998. The total of rainfall reached to 1,250mm. The small landslide occurred near the center of rainfall (**Fig.3.15**). The landslide has distinctive characteristics. The materials slipped down the valley head and valley bottom very quickly without any deposition and dissection, the body hit a building and broke the window and the inside, then the material ran about 150 meters and diffused as a thin debris bed. The gradient of the slip and transportation surface is very low (6 degree), the volume is small (2,500 cubic m) but the destruction force is very large. We think the force comes from the velocity. Thus we call the landslide rapid flow. 5 victims were in and around the building.

(4) Rapid flow on the valley fill deposit

There were two earthquake (May 26, 2003 and July 26,

Fig. 3.13 An overview of Sabuta landslide area Yamagata Prefecture eastern part of Dewa Mountains northeast Japan. (It keeps the clear shape of landslide features and the action occurred at the whole of the topographic area).

2003) at southern part of northeast Japan. Two landslides occurred at the occasion in each earthquake in artificially buried valley in Miyagi Prefecture (**Fig.3.16, 17**). These have similar characteristics as the case of former one. The sizes are small but long distances transported without crush, degree of apparent of surface is quite low. The velocity looks high. There is no doubt of much contribution of saturated water. Additionally, the two cases are occurred at the artificial buried valley. One area was used as the paddy field and the other was used for field and abandoned. It is needless to say the strength of cut and fill topography is deformed from the original one. We have to pay attention to them as a new geology. The strength of valley fill deposit should reduce and the new ground water condition changes compared with the initial one. Based on the two case studies, the valley fill for agricultural purposes is weaker than for the housing.

Fig. 3.14 An overview of Sumikawa Onsen landslide and debris avalanche. The landslide occurred at a part of landslide topographic area (Half of the body remains at the area and the rest moved away as a debris avalanche to the 2km downstream).

(a)

(b)

Fig. 3.15 Rapid flow landslide hit a building Fukushima Prefecture northeast Japan. (a); The source area of landslide stripped the slip surface and the body might be moved very rapidly on the film water. (b); There is nothing of any debris and no erosion. The materials transported to several hundred meters.

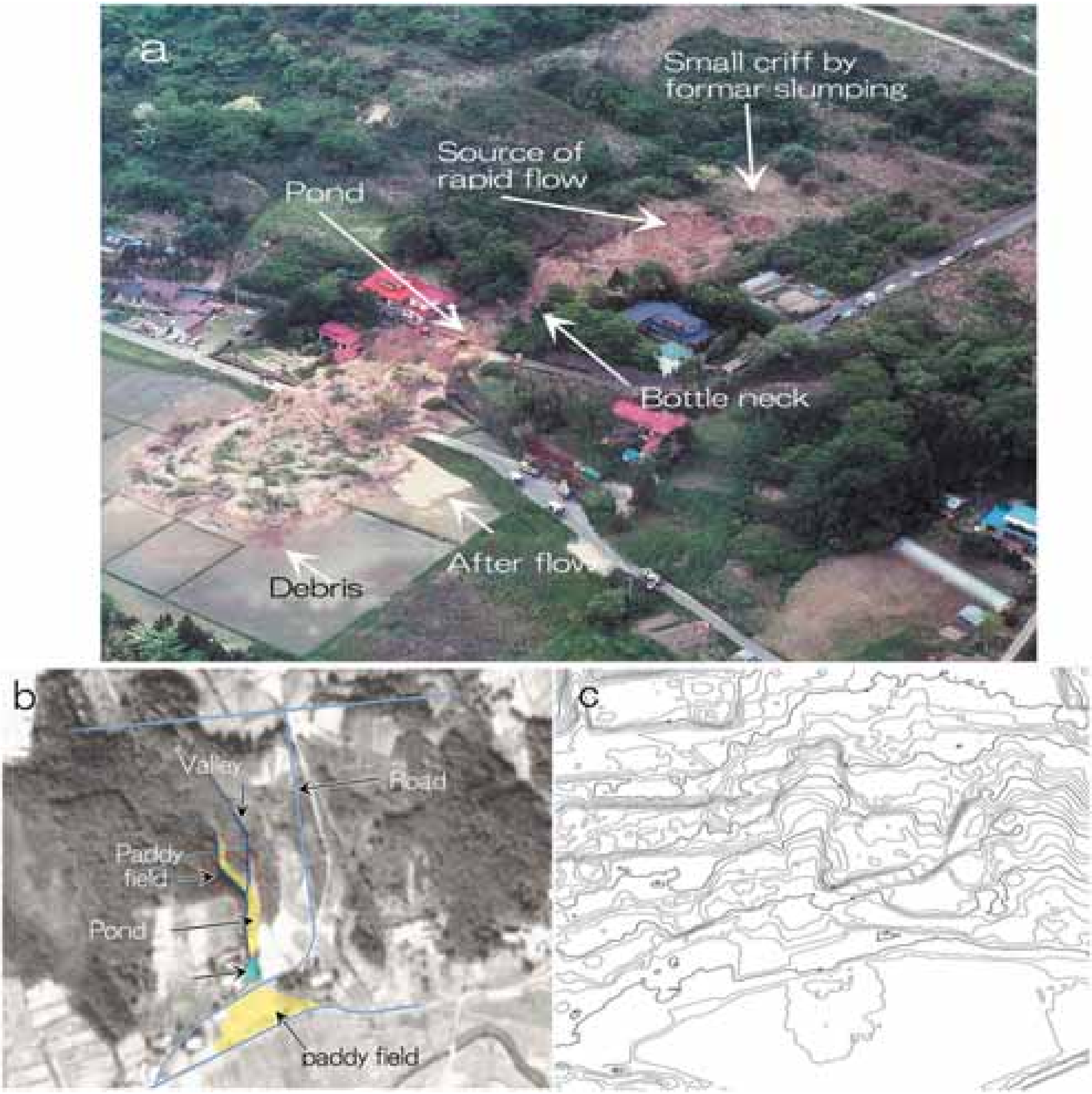


Fig. 3.16 Rapid flow landslide at the artificial reclaimed area by the trigger of earthquake on May 26, 2003 Miyagi Prefecture. a; An overview of landslide area just after the action (The photo is taken by Kokusai Kogyo Co., Ltd.) b; The landslide occurred at the reclaimed valley. The land modification completed 35 years ago for agricultural use. The former topography and land cover such as pond and paddy fields shows the highly potential of grand water. c; The 1 meter contour interval map (The map developed by laser data) shows the clear landslide topographies.

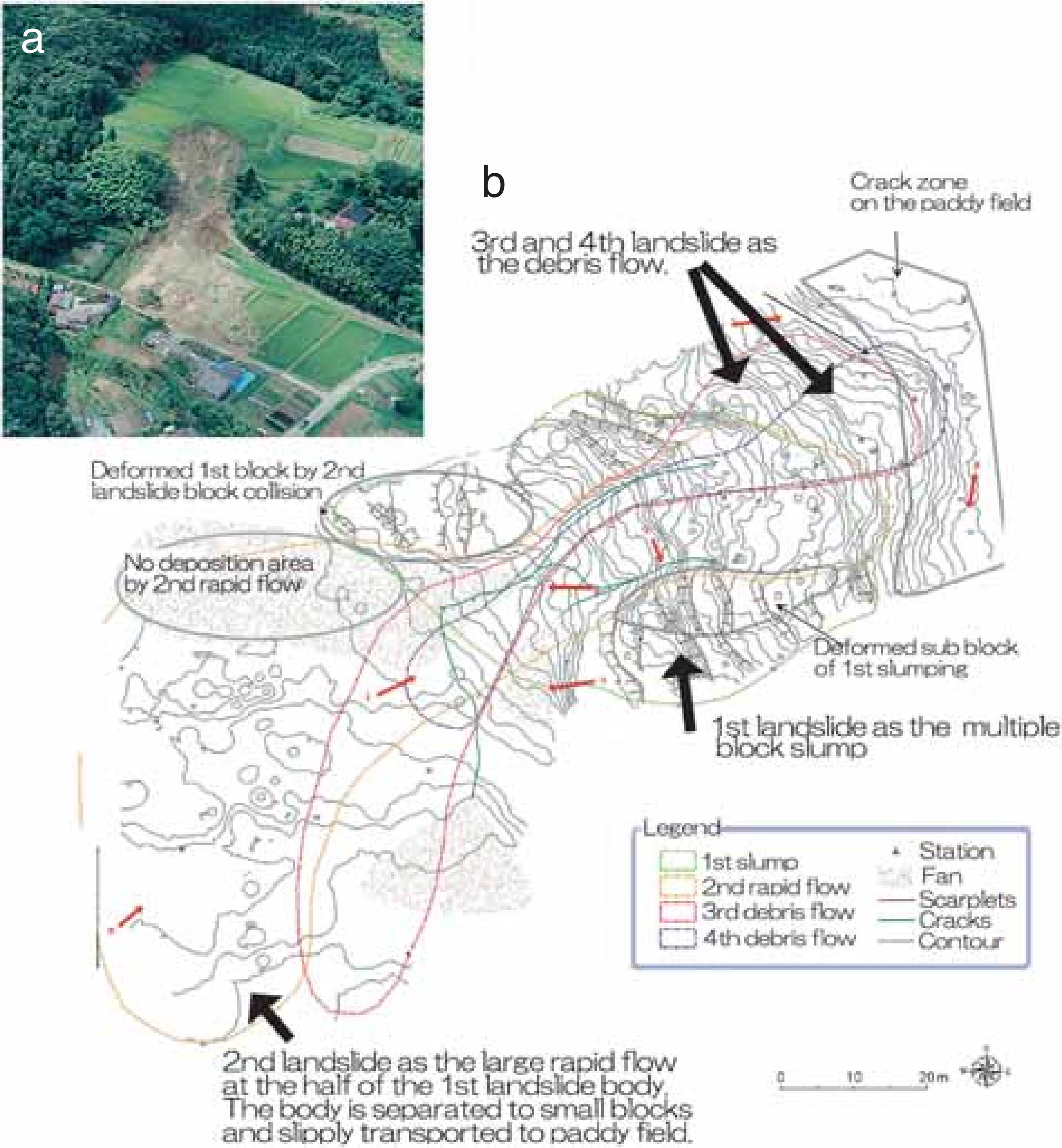


Fig. 3.17 Rapid flow landslide at the artificial reclaimed area by the trigger of earthquake on July 27, 2003 Miyagi Prefecture. a; An overview of the landslide area (The photo is taken by Kokusai Kogyo Co., Ltd.). The landslide occurred at the marginal part of paddy field which was developed 35 years ago by cut the hill top and fill the sideslope and hollows. (above) b; Detail of landslide topography the contour developed based on the field measurement by total station. The main shocks of the earthquake happened three times in one day. The heavy rainfall also hit there.

The initial landslide happened at the 1st main shock as a type of slumping. Many cracks developed at the paddy field and a large amount of water infiltrate from the paddy field and by the rainfall. The rapid flow occurred at the moment of 2nd shock. A half of the slumped body slipped down and transported to the plain. Few small surface landslides occurred after the rapid flow and the cracks are developing now.

4. Categorization of slopes and landslides

4.1 Approach to the land classification map

At the land surface, various factors related with geomorphic process, including artificial one, have effected on the establishment of landform. The land will never stop changing its form. If the landform as a land surface form can be regard as a representation of geomorphic process, it is possible to assume that geomorphic surfaces have been formed by various kinds of geographic processes at the land surface. For example, let us observe some slopes in a humid temperate region. Taking a look at a series of slope units leading from crest slopes into a valley bottom, along the longitudinal profile, it will be noticed that there is an area which has some common properties as to gradient, curvature, and type of curvature, etc. Here, let me introduce the notion of slope segment. It contains a crest slope with convex section, a valley bottom with platy section and a side slope with concave or linear profile sections which connect the formers. If the area of these Forms is arranged spatially, the land surface will be recognized as a mosaic of some landform units that can be defined in terms of some feature. Landform units will be captured objectively based on the geomorphologic characteristics of the unit itself and the boundary with adjacent units. Tamura (1969-2001), mainly based on his field inspection, proposes that valley head area will be made up of five or six micro landform units. Further, he argues about the maintenance and development process of the valley head area by analyzing the soil profiles and hydrological characteristics of these micro landform units.

4.2 Micro landform units of slopes without a large scale landslide

A few micro landform units, usually divided by a series of breaks of slope angle, are arranged in a longitudinal profile leading from crest slopes of original slope into a valley. Namely, there exist some micro slope units spatially on slopes. Based on the study of Tamura (1981a, b), it is possible to take the micro landform units of this slope to be **Table 4.1**. This figure shows that in a toposequence between the crest slope and side slope, there is always a convex break. Along the longitudinal profile leading from crest slope to valley bottom, there are convex breaks, whose gradient is steep toward the lower portion of sideslopes, between the boundary of crest slope and sideslopes. The boundary between the sideslopes and valley bottom or foot slopes is always divided by concave breaks suffering abrupt change of the slope angles downward. The side slope usually is divided into two areas through a convex break, upper sideslope and down sideslope. In humid temperate region such as Japan, most of surface failures occur on this lower side slope. Thus, Hatano (1978) named this convex break boundary "erosive front." Besides these micro landform units, a micro landform arrangement as displayed in **Fig.4.1.a, b** appears in a valley head area. These micro landform units have each proper Form and Material and they have been formed by some geomorphic process. Particularly, in the humid temperate region such as Japan, a lower sideslope is thought as the area where surface failures frequently happen. This will mean that the area of lower sideslopes was formed by some repetitive surface failures. Thus, it may be possible to propose that the ratio of an area of lower sideslopes shows the activity of erosion caused by a number of surface failures.

4.3 Illustration of micro landform units and the potential of photo interpretation

Here we will introduce an example of the result of relationships between the micro landform arrangements and slope failure occurrence in Sendai area. This area is known as a place where some catastrophes often occurred at; in 1984, a bush fire occurred and the most of vegetation was lost. In 1988, it had a heavy rainfall whose total amount of precipitation was over 800mm, causing more than 2,000

Table 4. 1 Significant functions and features of each micro landform unit. (after Tamura, 1993)

Micro landform	Preveiling water movement	Predominant geomorphic processes	Morphogenetic tendencies	Stability
Crest slope	Vertical infiltration Troughflow	Soil creep	Evolution of convex segments	Slghtly stable
Upper sideslope	Throughflow Overland flow	Soil creep Lateral eluviation	Maintenance of facets	Slghtly unstable
Head hollow	Throughflow Overland flow	Soil creep Lateral eluviation Surface landslide sheet wash	Subdueing of concave segmment Formation and maintenance of micro-facets	Unstable Complex of deposition and transportation to channel
Lower sideslope	Throughflow Overland flow Lateral infiltration Saturation oveland flow	Surface landslide Seet wash	Outbreak of new valley-heads	Extreamly unstable
Bottom land	Oberland flow Throughflow Pipe flow	Debris sedimentation Gully erosion Flooding	Down-undercutting Temporal accumulation	Very unstable Complex of erosionand and sedimentation

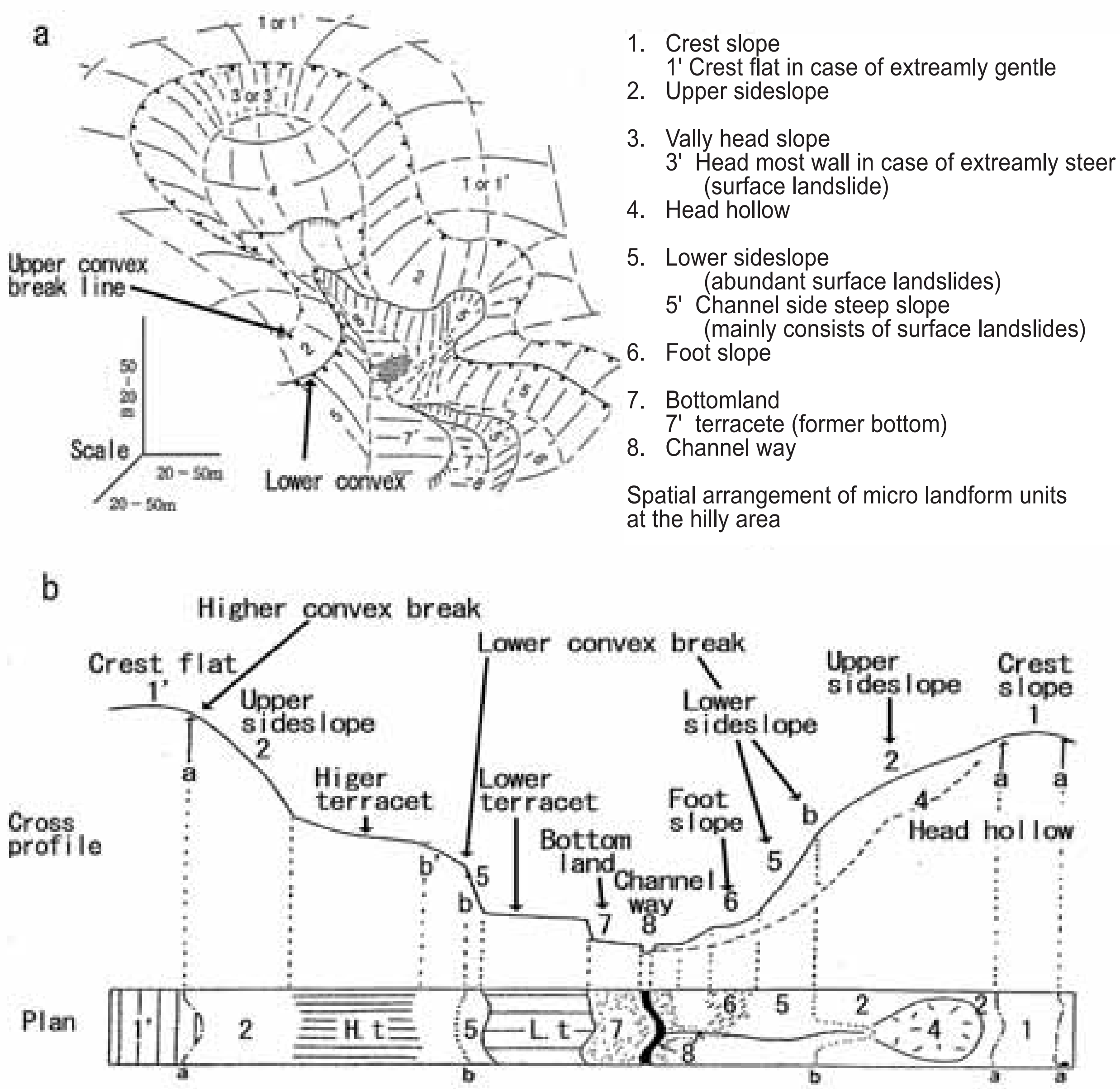


Fig. 4.1 Schematic explanation of the arrangement of micro landform in hilly area (after Tamura, 1993). a; Spatial arrangement of micro landform units at the valley head in hilly land. The units have own location an the boundary has a characteristics of the abruptly change the slope angle. b; Cross profile of in case of the semi small scale landform units component. The landform classification must carry the identification of the each landform unit and explain the spatial arrangement and evaluate the meanings of the functions.

slope failures over 860ha. **Fig.4.2** shows the results of photo interpretation about a part of this area. The micro landform classification map mentions the several distinct convex break boundaries of the landform units such as the boundary between crest slope and upper sideslope, or between the upper and lower sideslope etc., and slope failure caused by the heavy rainfall. **Fig.4.3** summarized the relation between the spatial distribution of slope failures and micro landforms. More than 90% of total amount of slope failures had occurred at the lower part of the convex breaks between the upper and lower sideslope. **Fig.4.4** and **Fig.4.5** shows the micro landform classification and the aerial photographs at a part of **Fig.4.2**. We are able to see the slope failures micro topography originated at the lower sideslope. This will mean that the down sideslope area was formed by the repetitive surface failures. Thus, it may be possible to assume that the ratio of the area of lower sideslopes and the drainage area shows the activity of erosion caused by a number of surface failures.

4.4 Categorization of landslide phenomenon

The slope failure, scar and landslide could be regarded as a series of mass movement. **Fig.5.3** shows a typical image

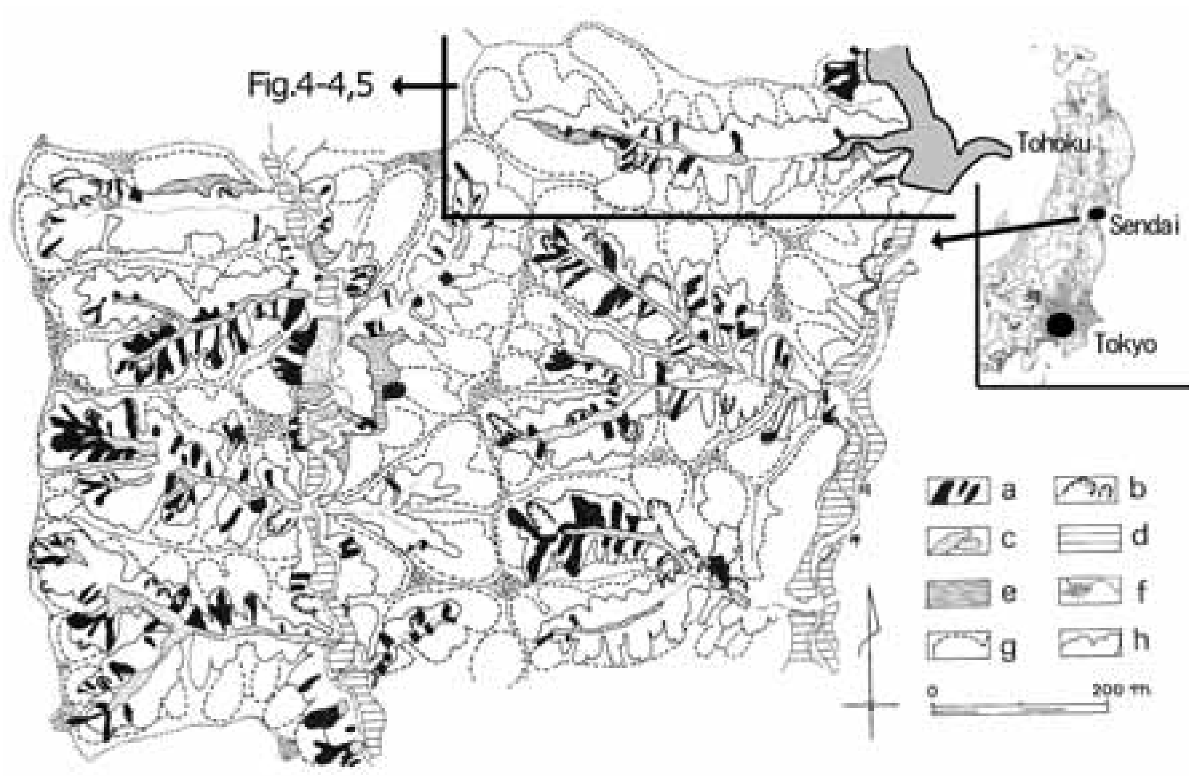


Fig. 4.2 Micro landform especially the convex breaks classification and surface landslide at the heavy rainfall event in August 1988, Tomiya Hills Sendai City, Japan.
a; Slope failure at the event b; Slump type landside at the event c; Earth flow depositional area in the bottom by the event d; Alluvial plain e; River terrace f; Crest flat g; Upper convex break line h; Lower convex break line.

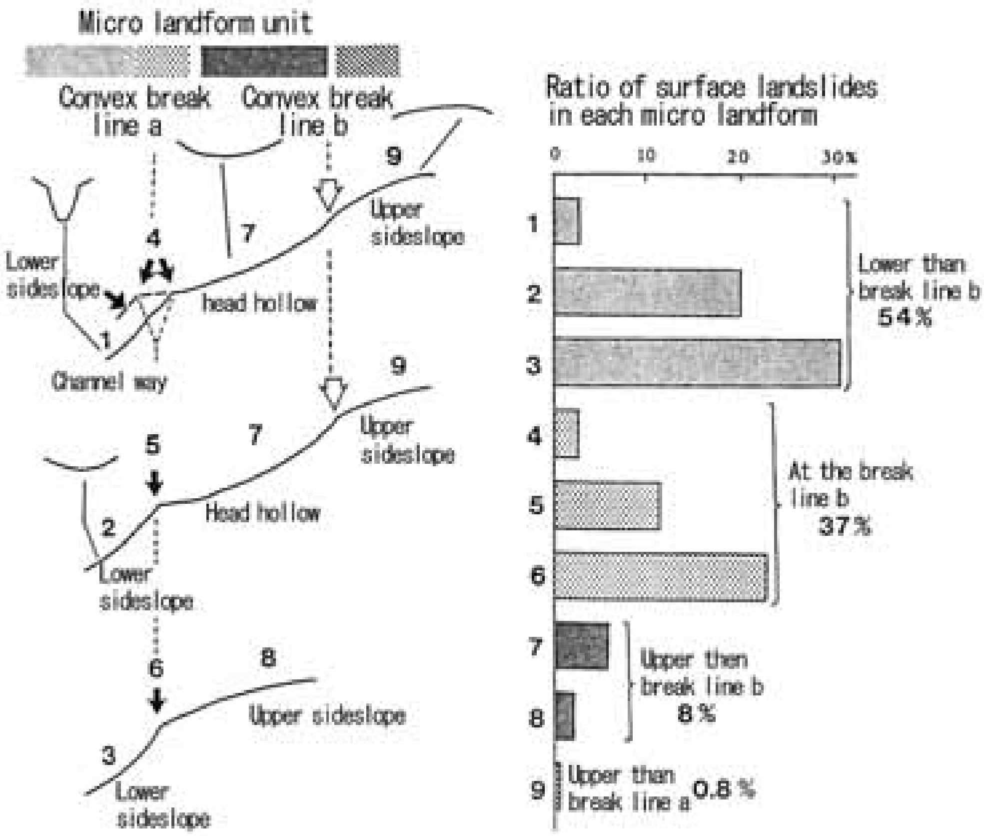


Fig. 4.3 Ratio of surface landslides in each micro landform units.

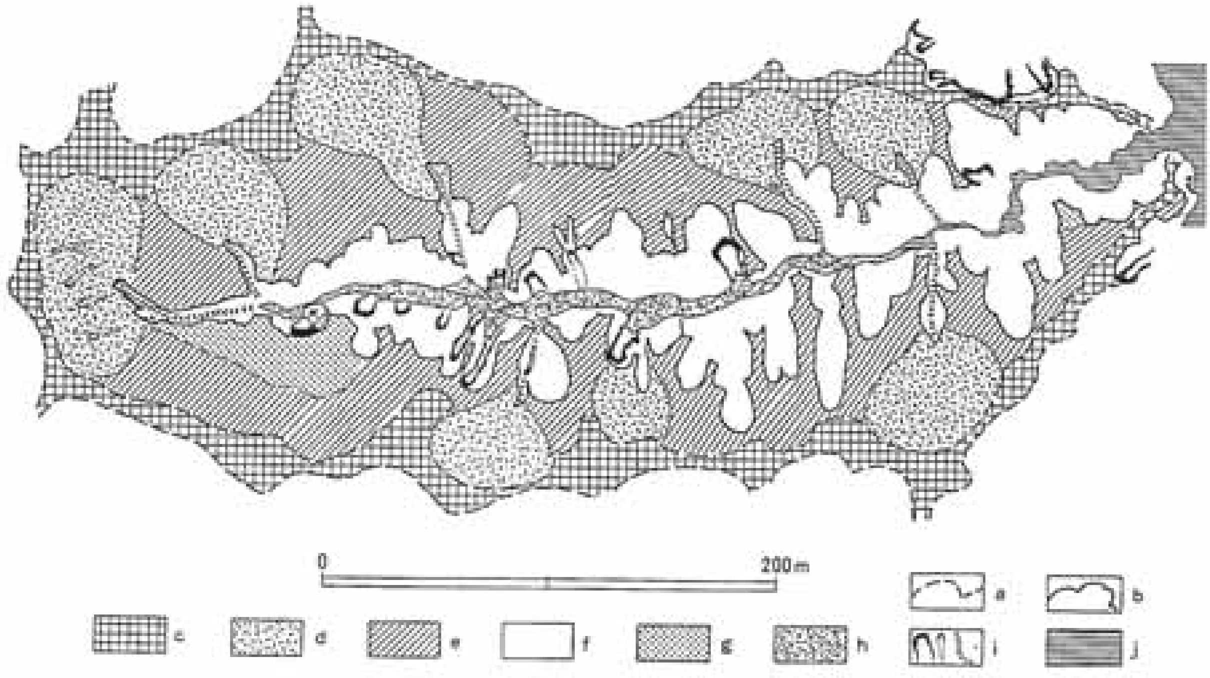


Fig. 4.4 Detail of micro landform classification map at a part of **Fig.4.2**.
a; Upper convex break line b; Lower convex break line c; Crest slope d; Valley head area e; Upper sideslope f; Lower sideslope (the area mostly consists of former surface landslides) g; Foot slope h; Bottom land i; Surface landslide, gully j; Water surface.

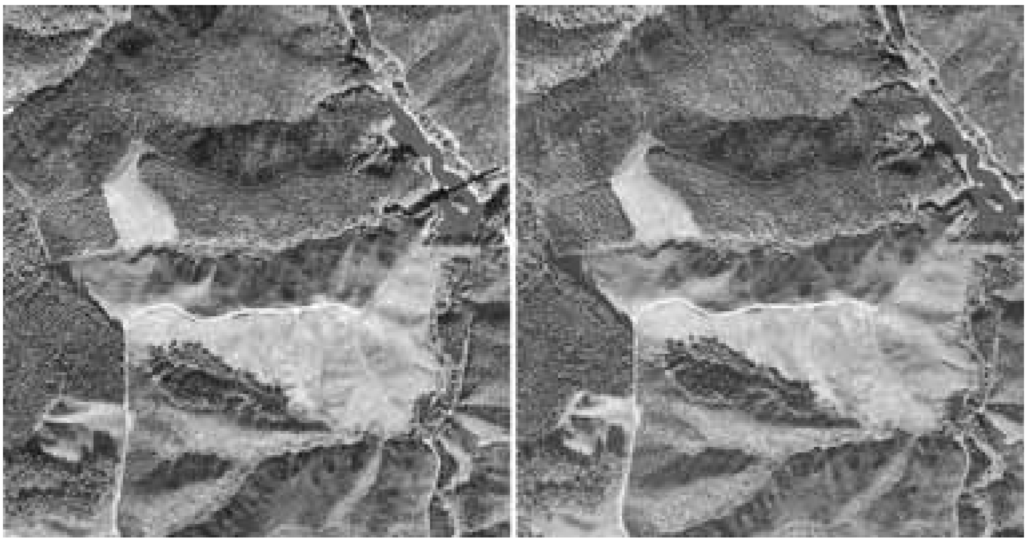


Fig. 4.5 A stereo pair aerial photographs of the **Fig.4.4** area (arrow shows the location of valley).

of the categorization. In general, there are various kinds of categorization. The term of "Landslide" is also has two meanings. The Japan Landslide Society announced the new identification of Landslide, i.e. all sorts of mass movement excluding those originated by perglacial processes, earth flow and soil creep, though, the term of landslide is used as a large-scale landslide before the new definition. The usage of the term in this report will be according to the **Fig.5.3**.

4.5 Introduction of surface failures and soil erosion as a mass movement on slope areas

Fig.4.6 shows mountain slopes in Japan. It can be easily identified that a number of surface landslide occurred on a part of the slope. Identifying this area in three dimensional way, as well as above example, it will be recognized that

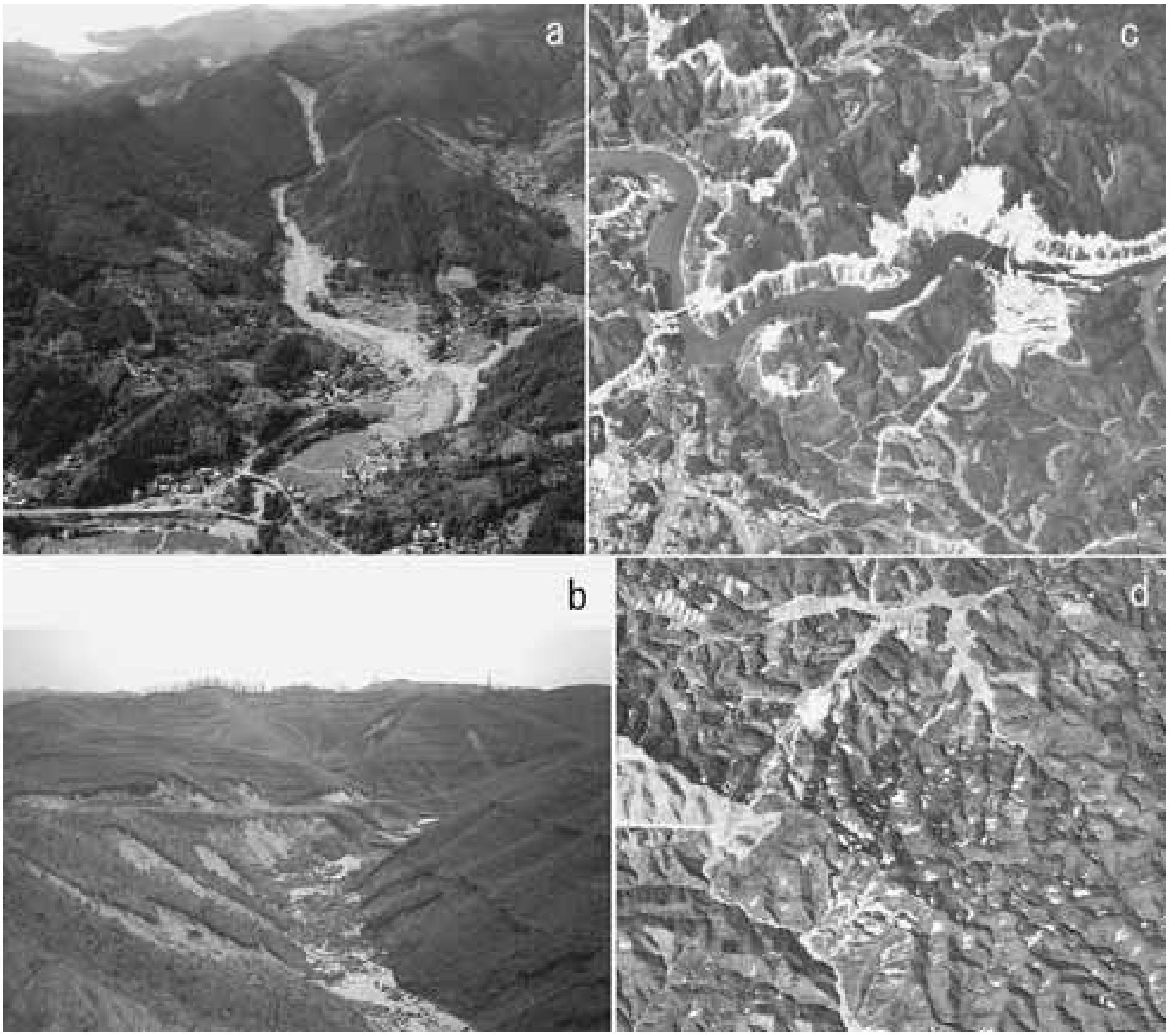


Fig. 4.6 Examples of surface landslides in Japan. a; Relatively large surface landslide and large scale earth flow at Minamata Kyushu b; Surface landslides at bare hill slope Tomiya Hills, Miyagi Prefecture c; Many scars distribute along the water reserve at Chubu district d; Many scars occurred by heavy rainfall at the hill side slope in Kinki district Japan.

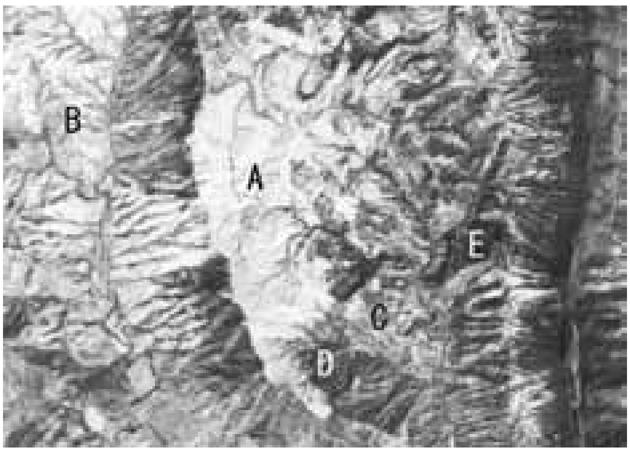


Fig. 4.7 An aerial photograph at mountain side of Lomsak basin Pechabun province, Thailand. The area classified into five levels of land cover. A to C is degraded vegetation area especially A is completely changed to bare or grass land. Tree line can be seen just along the channels. B is the vegetation coverage is slightly higher than A. Although there are many bared stripes or patches that seems as a features of surface erosion. The land cover type A and B, the strength of grasp of soil by tree roots must be reduce and the surface runoff and infiltration getting quickly, it will lead the surface erosion and surface landslide. D and E is still keeps the forest.

a lot of surface failures have occurred near the break line on the sideslope. On the other side **Fig.4.7** displays soil erosion at Pechabun area, in the middle of Thailand. But a clear break cannot be identified in this figure. This suggests that surface failures as displayed in **Fig. 4-7** rarely happen here in geo-historically. However, this picture shows that in the broad area of the slope, the vegetation was strikingly destroyed and the corresponding area became bare and grassed. Thus, it may be possible to predict the potential soil erosion and surface landslide like a Phipun basin at each micro landform unit by means of the classification of micro landform units on slopes.

5. Photo interpretation of large scale landslides

5.1 Identification of landslides

Examples of the landslide topography.

The large scale landslide is a mass movement phenomenon, which occurs when a part or the whole of a slope moves as a mass through landslide surface. Landslide surface distributes between the landslide body and bedrock. The surface develops sliding clay like a thin film layer. In Japan, locates in the humid temperate region, the soil usually develops on the surface of slopes. Thus, small creeps or surface failures that occur on the soil layer should be distinguished from the landslide.

First, in order to get clear understanding, we will display a slope without landslide topography. **Fig.5.1**, which displays slopes in the Kitakami Mountains, shows that a platy area of slideslopes widely distributes and ridges and drainage system are arboreal. Any obstacle that disorders the spacious arrangement of micro landform units cannot be found. However, if a landslide occurs on a part of the slope, some break lines of slope will disturb the arrangement of the slopes on the half way of them. Or, if a relatively large scale landslide occurs, the situation will be found that ridges and the valley arrangement are disordered. **Fig.5.2** displays schematically a slope that constitutes an area of the Shirakami Mountains. In this figure, a behavior of slopes will be found; a series of micro landform units leading to crest slope from valley bottom, that is, a group of crest slopes, upper sideslopes, lower sideslopes and valley bottom land etc. are displayed. Furthermore, small failures, a talus below those failures and a larger landslide are illustrated. Among these, lower sideslopes are in fact combined by some small slope failures. Landslides are essentially analogues to failures. But they differ in that the latter is a surface failure mainly resulted from failures at lower sideslopes which exfoliates soil layers, but the former causes a large deformation to slopes since the landslide deforms base rocks deeply and largely. For instance, in the case of landslide A, there is a steep slope (main scarp) which forms a clear break line, breaking the rounded and convex slope in the upper slideslope. At the bottom of this slope, a landslide body is illustrated. The identification of landslide topography is based on the understanding about "the behavior of slopes from crest to valley bottom which follows no landslide."

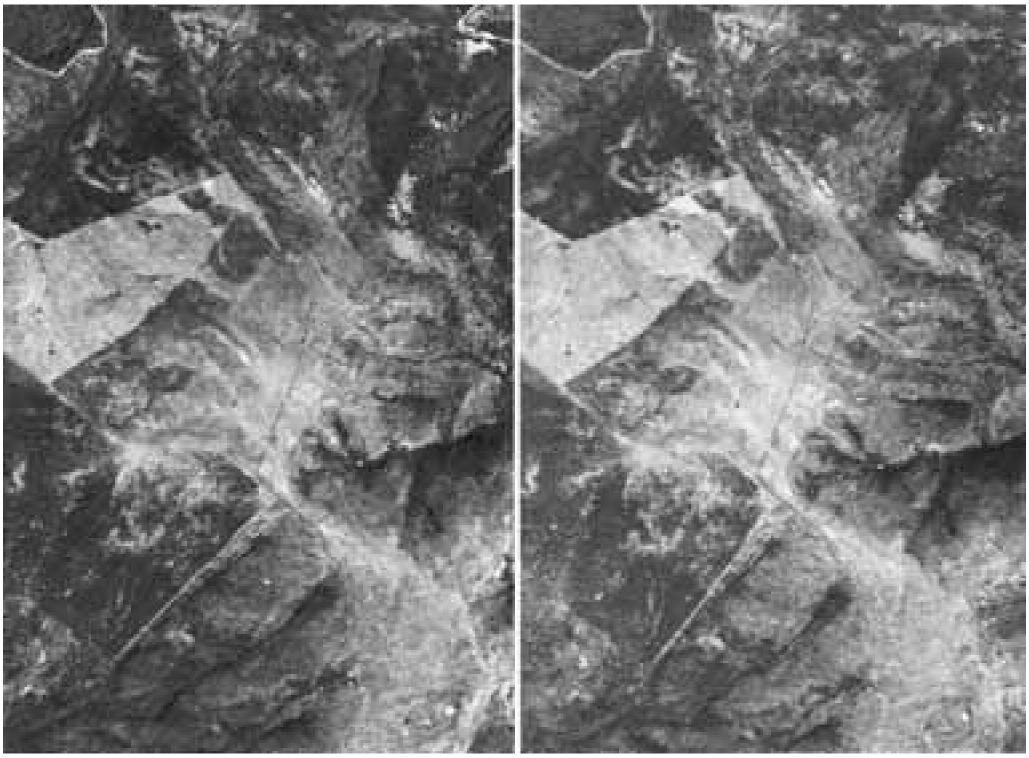


Fig. 5.1 A stereo pair aerial photographs in case of non large scale landslide topography in a part of Kitakami Mountains northeast Japan.

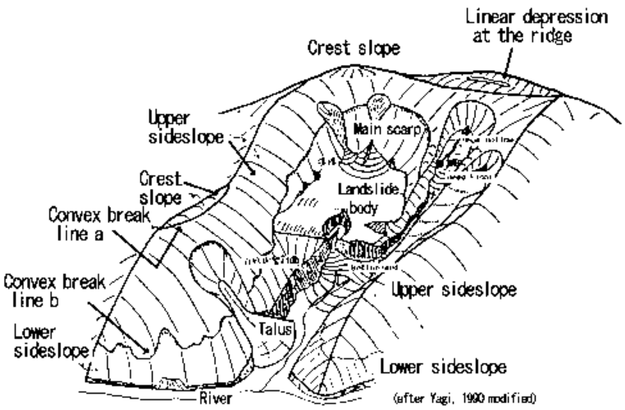


Fig. 5.2 A typical landform component including landslide topography (after Yagi, 1990).

That is, the landslide body should be identified as a factor of disordering the later topographical arrangement.

5.2 Landslide topography and geological framework

Needless to say, the landslide process causes large natural disasters. However, slopes formed by a landslide, on different aspects from landslide activity, is often unstable since they have some different dynamic characteristics as to weathering process, hydrological system, and rocks, compared with some other slopes. Namely, they are destroyed easily in comparison with other slopes, causing often earth flow, soil erosion and surface failures. On the other hand, at a mountain area in the humid temperate monsoon, complicated topographies and hydrological condition yield a land which suits a small paddy field, making possible a lot of people to dwell in the landslide topography.

It usually takes several ten thousand years before the landslide activity come to an end. Also, its actual activity is intermittent. Thus, the landslide should not be identified only in terms of disaster prevention. Rather, it will be necessary to observe and understand each landslide's characteristics, movement process or material. This movement will be naturally reflected on the form of landslide. Thus, precise identification of the landform by aerial photos or other means will enable to understand the characteristics of landform to some extent. Varnes (1978) and Turner and Schuster (1996) etc., from these points of view, classify the landform topographies and their movement process, obtaining good results. **Fig.5.3** summarizes the main types of movement processes and those structures proposed by Varnes (1978) and Turner and Schuster (1996). As these photographs displays, the landslide topography seems to have the formal properties that are easily distinguished from other slopes around it. And there seems to be a certain correlation between its internal structure and the land surface form. **Fig.5.4**, which is an example of a landslide topography formed by movement of simple slump type, shows the names and structures of each part which constitutes the landslide micro topography. They will be a help to understand the land topography further.

5.3 Landslide topography through aerial photo interpretation

The distribution of a large-scale landslide can be grasped through aerial photo interpretation since it can be quite clearly distinguished from non-landslide slopes around it. In this section, we will introduce photo interpretation about some typical landslide topographies.

First, we will present an example of huge landslide by means of landscape photograph (**Fig.5.5**). A mountain slope, extending from the left top of this photo, is broken sharply by a large steep slope. This steep slope is the main scarp which divides surrounding stable slopes and the area of landslide topography. In front of the main scarp, there is an uneven landslide body with various scales. This area is a landslide body. There are two ponds between the landslide body and the main scrap. The movement of the landslide body dammed rivers, leading to form the pond A. Pond B is located at the trench shape depression in front of the main scarp which is established by water concentration there. **Fig.5.6**, a stereo pair photograph, shows a large scale landslide formed by breaking a gentle slope. This landslide topography provides various information about the landslide process, its material and the landslide mechanism of the landslide body.

A stereo pair photograph is the example of one block slump which is yielded by breaking a gentle slope. In the lower part of this photo, there are a white winding path and a large scale steep scarp. A landslide body is the area between this large scarp and a river which runs right down from the middle of this photograph. The landslide mechanism of the body (mechanism of slumping) can be identified on the following properties; 1) the land surface of the landslide body shows uphill-facing inclination, 2) the gradient of cliff is gentle in the area corresponding to this uphill-facing inclination body and the left side of the cliff is almost vertical in the area paralleling with the narrow path.

From these observations it is obvious that this landslide body forms the main scarp which shows a gradient of about 40 degrees nearly above from the middle of this photo and that one large scale block caused a simple slump movement. Thus, the vertical cliff in parallel with the narrow path can be thought as a lateral cliff. There is a pond directly under the main scarp. This pond was formed as a result of uphill-facing inclination of the body. Thus, there is a possibility that this landslide have occurred in the very near past, since the landslide body, the main scarp and the pond are hardly covered by terrace deposit yielded after the cliff formation and the erosion of landslide cliffs is not identified clearly.

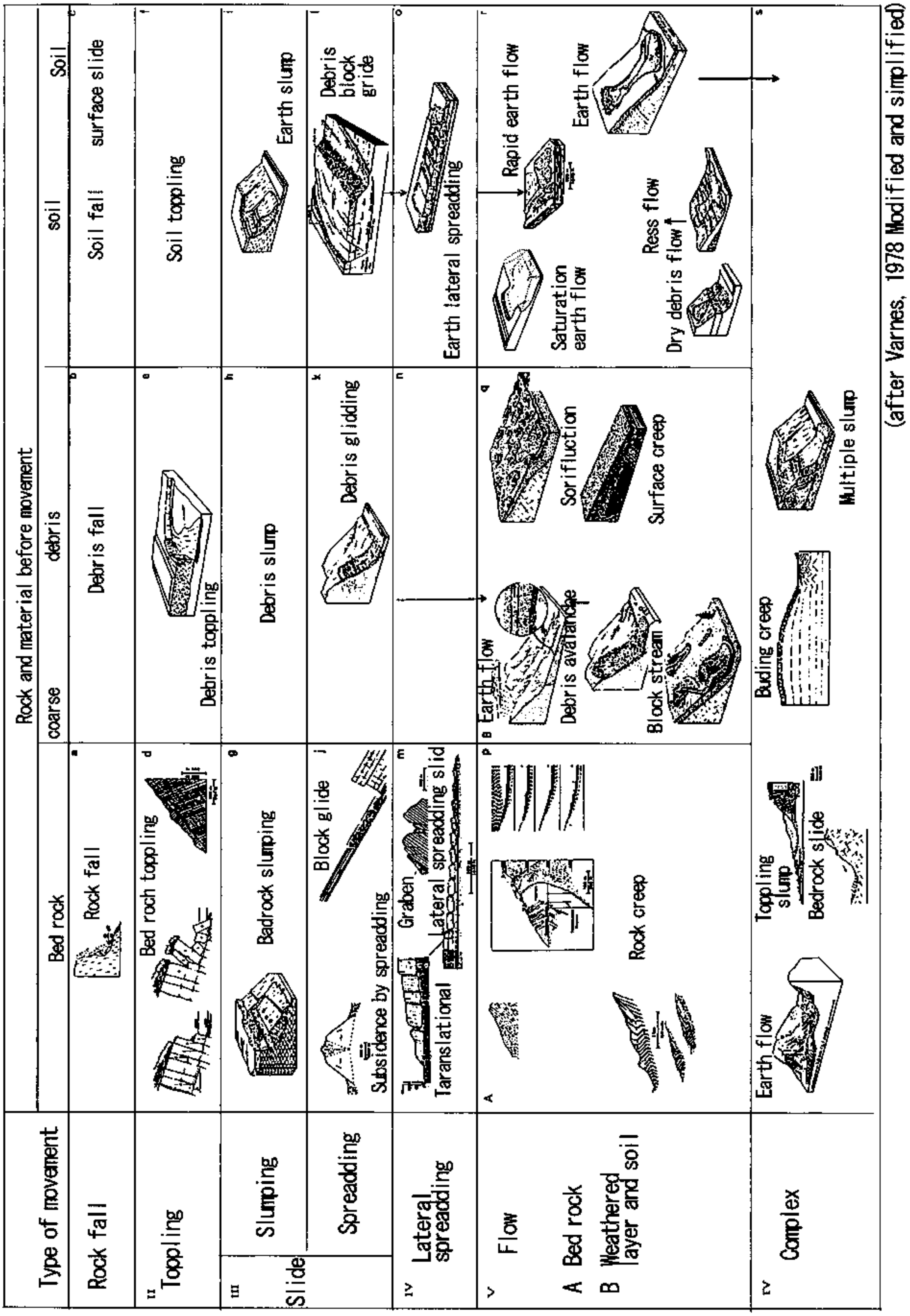


Fig. 5.3 Landslide types and classification.

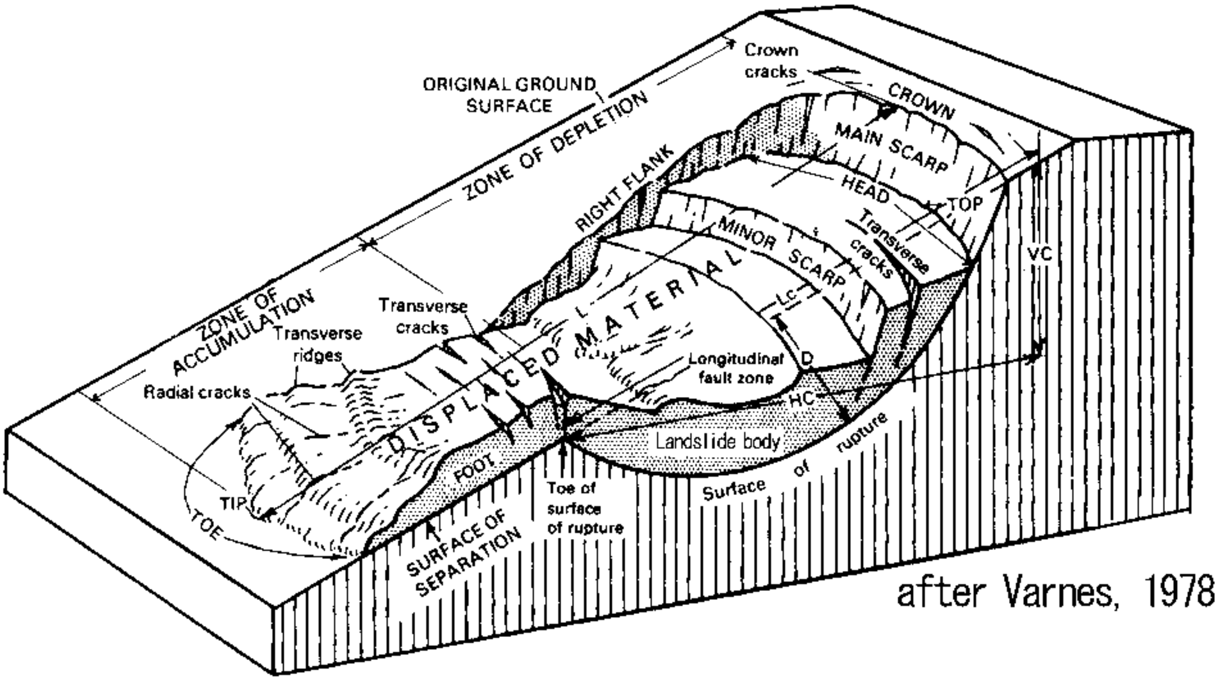


Fig. 5.4 Block diagram of idealized complex earth slide to earth flow (after Varnes, 1978).

Fig. 5.5 An overview of typical "large scale landslide topography". Shironuma landslide area distribute at the foot slope of the Funagata volcano, Miyagi Prefecture northeast Japan.

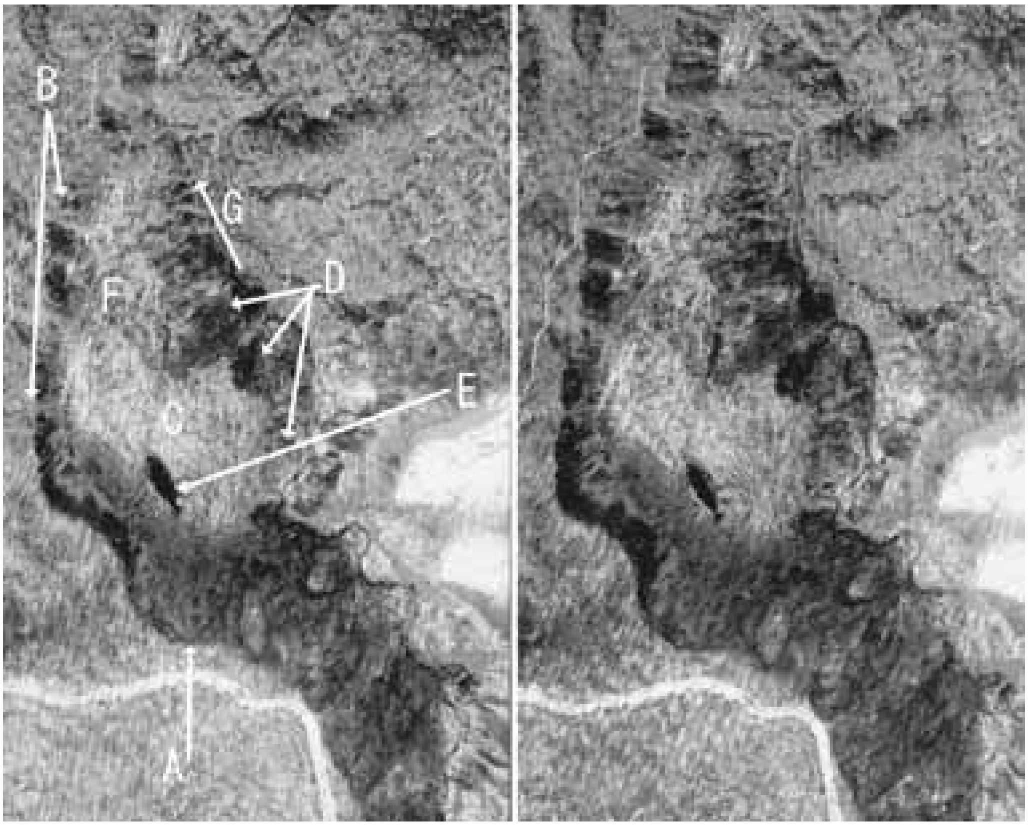


Fig. 5.6 A stereo pair aerial photographs of "Flesh landslide topography" The landslide topography should be identify in two dimensions. 1st is the outline of landslide topography. The distribution map of landslide topography which is based on the identification. 2nd is the interior microlandforms. Interior means not only the landslide body but also the main scarp and adjacent slopes. The main components of landslide landform and the characteristics of their boundary can be identify and easy to deduce the geological modification of the landslide body.
A; Boundary of main scarp and upper normal slope keeps the sharp edge but without any crack. The surface of main scarp has poor vegetation and the angle is moderate compare with the lateral scarp
B; Landslide body generally keeps the original relief but the inclination of the surface appears the tendency of backling. The small parallel ripple shape relieves appear at the body surface.
There is no talus deposit at the boundary of two major landforms. The toe part of the body is face to the river. There are many slope failures along to the river. F seems that the tendency of the separation from the main body by cracks.

5.4 Distribution map of landslide topography

Landform classification map, which identify and illustrate the landform topography, National Research Institute for Earth Science and Disaster Prevention, Japan have formed the landslide classification map with a scale of 1/50 thousand and published those in order, since 1982. This has contributed to proceed the understanding of the landslide distribution in the country (NIED,1982−2003). **Fig.5.7** shows the distribution of landslide topography in Tohoku district (Landslide society Tohoku branch, 1992).

5.4.1 Explanation on the symbols on landslide Maps

The map includes four aspects with regard to recognition and identification of landslide topography; exact mapping for location and shape of landslides, fundamental landslide structures, grade of dissection of the landforms and the relationship between connected landslides. Mapping is mainly dependent on geomorphologic interpretation of aerial photographs on a scale of approximate. 1:40,000. Key location were surveyed in the relevant fields.

Recognition of the precise shape of a landslide is essentially based on proper identification of landslide structures, especially boundary structures, of which the most important are the main scarp, flank, lateral ridge, foot (or toe of the surfacerapture) and toe. Most important in landslide mapping is the identification of and representation of the main boundary structure for a unit landslide landform. Therefore, it is drawn with thick lines (curves). General rules for the symbols on landslide maps are shown in **Fig.5.8**. The crown of a main scarp and its extension flank or lateral scarps are shown by thick lines. A fresh and continuous

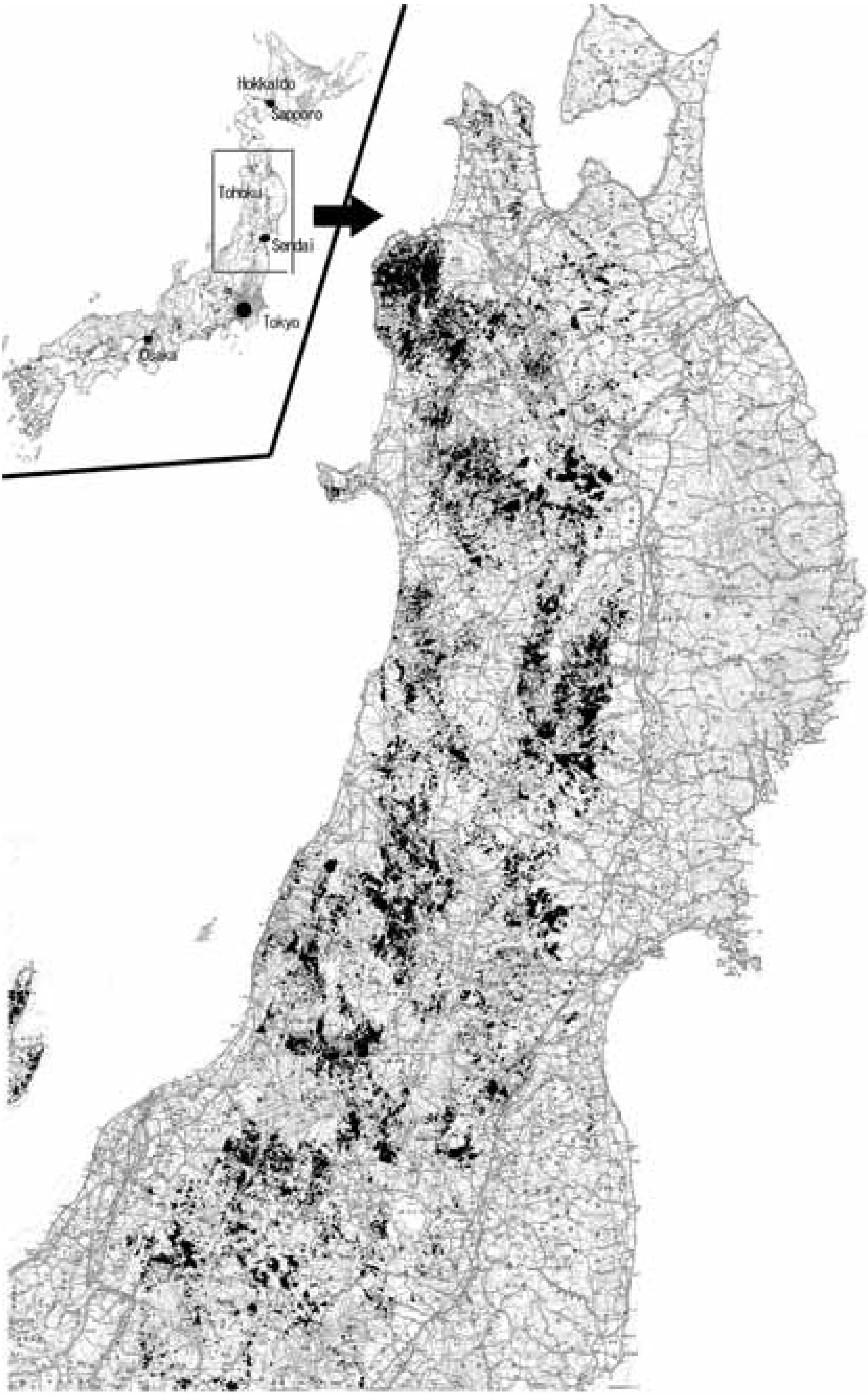
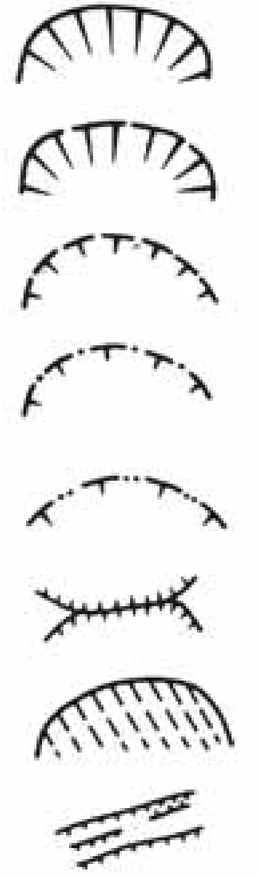


Fig. 5.7 Distribution of the landslide topography in Tohoku district (after the Japan Landslide Society, Tohoku branch, 1992).

I. Boundary structures

A. Main scarp and lateral scarp (Frank)



1. Main and/or lateral scarp
   of which crown is fresh of not dissected
2. Partially dissected crown
3. Mostly dissected crown
4. Roundly subroundly and vague crown
5. The missing part of the scarp and crown by
   dissection
6. Joint crown which divides two main scarps
   throwing opposit slope directions
7. Exposed slide surface without sharp scarp; dip
   of the slide surface is usually gentle (<25°):
   The crown is defined by the intersection
   between the opposit slope and the slide surface
8. Lunar on crown cracks, multiple scarps and
   ridges

B. Margine of landslide body

1. definite and probable margin of the
   landslide mass with a main scarp at
   the backward or upper slope
2. The quetionable part of the margin is
   shown by a question mark "?"
3. Landslide body margin without main scarp and
   crown symbols:
   Margin of residual part of the mass of which scarp
   has been almost eroded away
4. A part of the margin overlain by another moved body
   or deposit
5. Margin of a mass movement at the initial stage from
   the original slope. Probable boundary of an area
   inferred as an unstable or quasi-moving mass without
   clear detachment structure between the body and
   bedrocks
6. A mountain or hill difficult to identify whether mass is
   moving or not
7. Foot line or toe of surface of rapture: usually by the
   landslide body

Fig. 5.8 Symbols of the boundary structure for landslide topography mapping (after NIED, 1998).

crown is drawn by a continuous thick line (**Fig.5.8 I.A.1**). If a crown is discontinuous with dissection by gullies or small valleys in the case of a somewhat aged landslide which has been more or less eroded, lines must be broken with intervals of the same lengths on the map as the widths of the dissected parts of the crown (**I. A. 2**). A crown dissected by many gullies or small valleys in an advanced stage of erosion is shown by a thick dashed line (**I. A. 3**). Rounded and/or vague crowns in more advanced stages of erosion are depicted by a single-dot-dash-line (**I. A. 4**), if landslide deposit remain on the downward slope.

We often encounter cases where broad missing parts of a crown require mapping because of a large area of landslide deposits needing reference to show the source of area of the deposits. In such cases, a double—dot-dash-line is used (**I. A. 5**). The steep surface of scarps are usually shown by hatches thinning toward downward slopes (**I. A. 1-6**).

In case of a translation slide on a gentle slope underlain by stratified sedimentary rocks, "nagare-ban suberi" in Japanese, a gentle slope is identified as an unloaded slide surface without a steep main scarp. Parallel-dashed lines are used to indicate this type of slide surface (**I. A. 7**). A lunar or crown crack is shown by thick lines with short hatches. A multiple scarp or ridge is also represented with the same symbols as a lunar or crown crack (**I. A. 8**), however they can be distinguished according to their pattern and location on slopes.

5.4.2 Examples of landslide classification map

In Japan, a number of landslide classification maps have been published before this map was. Early maps include Hatano (1972), Terado (1978) and Miyagi (1979)'s landslide topographies in Miyagi Prefecture before the work of NIED.

Fig.5.9 is a sample of the map at Aomori area consists of Miocene sedimentary and volcanic rocks (Shimizu *et al*, 1982) and **Fig.5.10** also is an example of the map in a part of Iwate Prefecture (Iwate Pref. & Japan landslide Society, 2002).

As the study about the distribution of landslide topography based on aerial photo interpretation proceeds, it has been recognized that different types of landslide topographies covers widely on slopes. As a result of this, it was argued that there is a relation between landslide topographies which are widely distribute and landslide disasters which sometimes occur. In recent years, the fruits of the study enable us to realize that most of landslides occurred in Japan will result from the reactivity of a part of an aged landslide topography, leading to the recognition that it is important to understand landslide topographies.

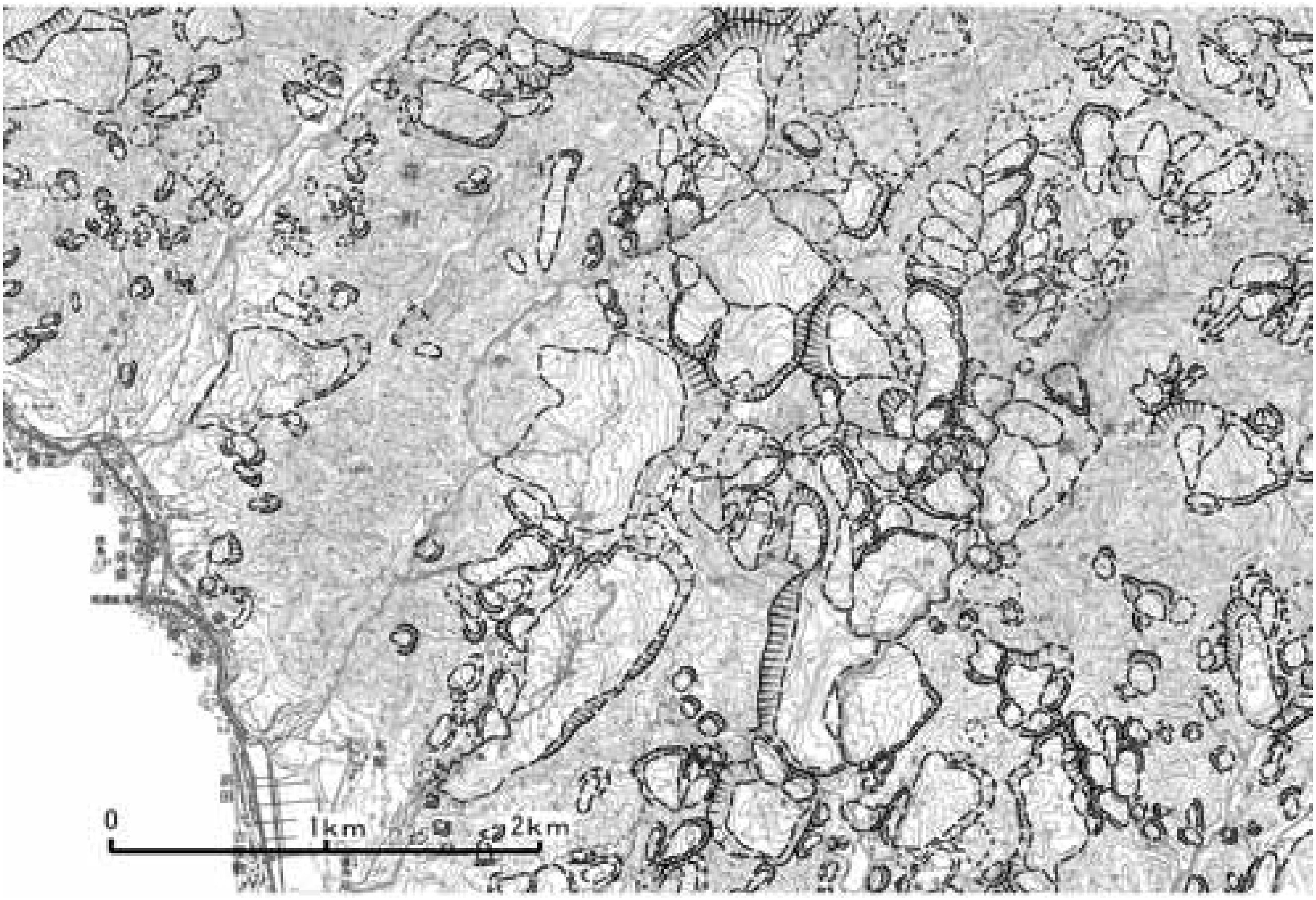


Fig. 5.9 Sample of the landslide topography map of a part of Aomori Prefecture (after Shimizu *et al*., 1982).

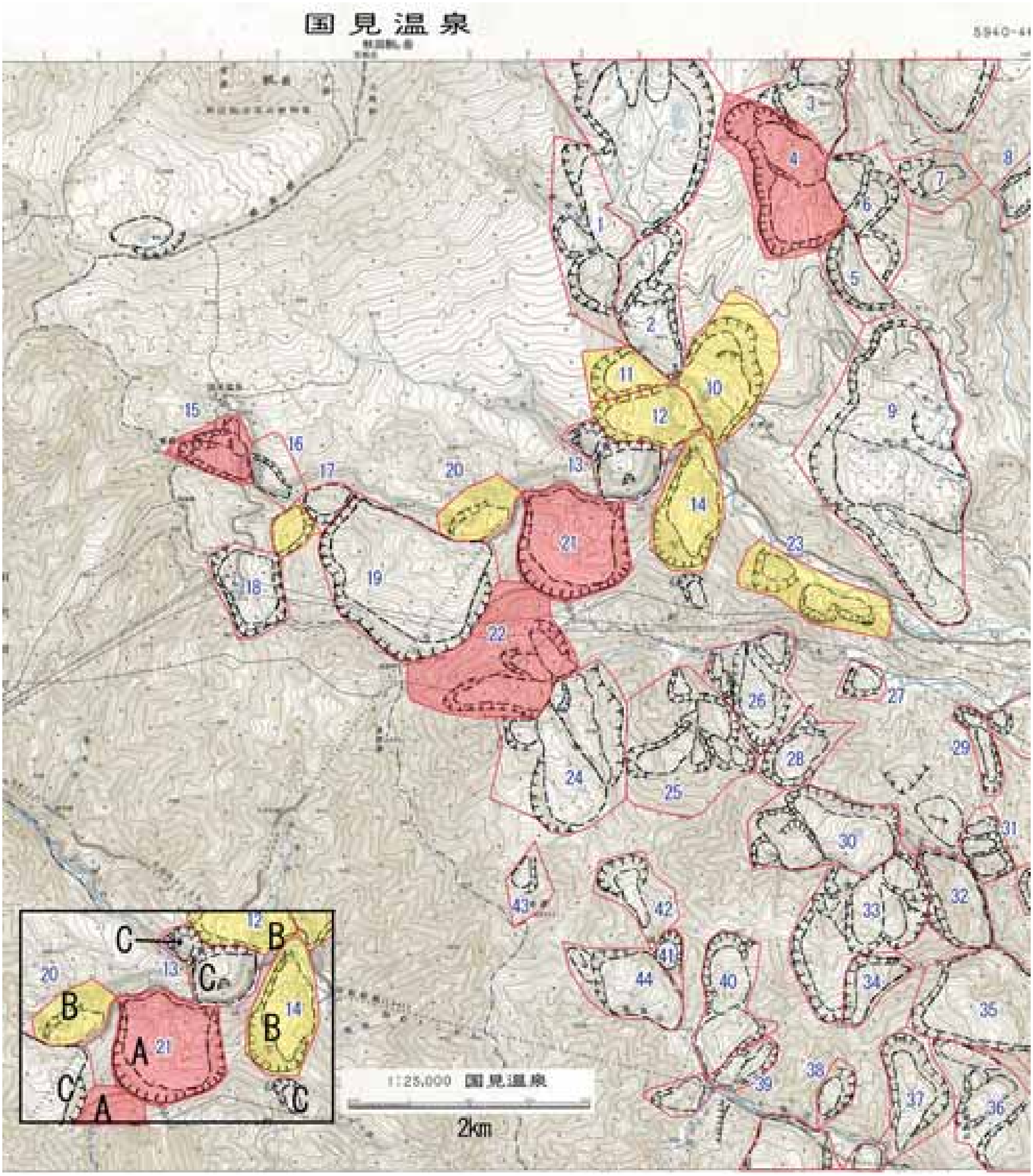


Fig. 5.10 Sample of the landslide topography map which categorized to the three levels of the potential of reoccurrence of landslide action (after Iwate Prefecture, 2002).

Let us introduce here a case of landslide occurred at the Sumikawa spa, in Akita Prefecture in May, 1997. This area was identified as a landslide topography in the scale of 1/50thousand distribution map of landslide topography "Hachimantai", published by National Research Institute for Earth Science and Disaster Prevention, Japan in 1984. The landslide at Sumikawa spa seems to have been occurred by the reactivity of the landslide area, displayed as S in **Fig.5.11, 12**.

The landslide can be regarded as a series of mass movement from geomorphologic viewpoint. This is similar to the processes of the autonomous destruction which

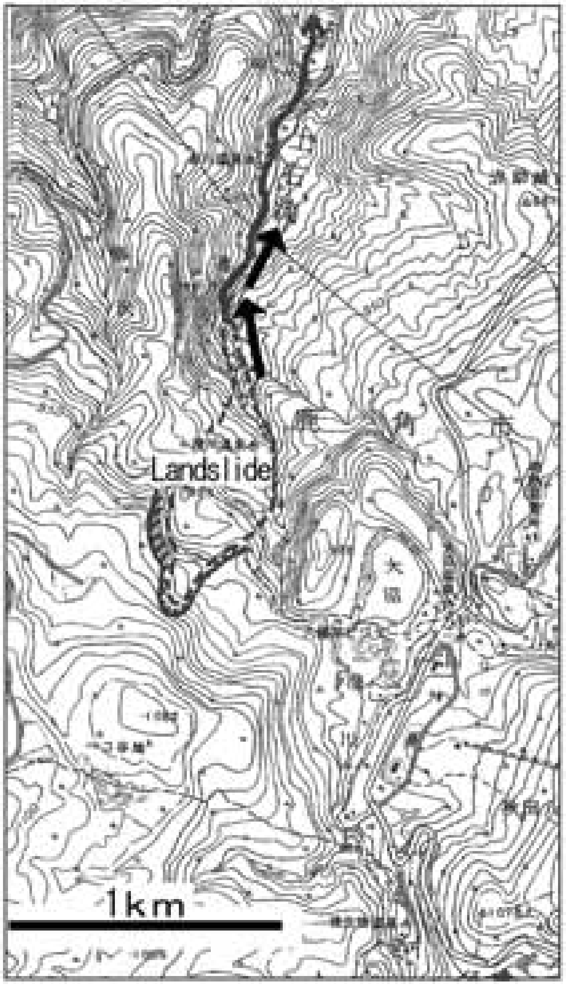


Fig. 5.11 Relationships between the landslide and landslide topography. The area mentioned of the recent landslide occurrence area in Sumkawa Onsen (after Inokuchi, 1998).

Fig. 5.12 Landslide topography map of the area in **Fig.5.12**. The landslide which has mentioned in **Fig.5.12** occurred at the marked place. This is an example the ability of forecast the landslide reoccurrence (after Inokuchi, 1998).

Initial situation (Stress field, solid-state of rock, Geology) Geomorphic setting (Stages of geomorphic development) Slope gradient										
Autonomous destruction process		Solid-state of rock	Destruction			Landform features			Triggar of action	
			Type	Scale	Frequency	Plan	Scarp	Micro landform	Outer	Inner
Stage I	Release from residual stress	Elastic	Destruction dominant	Large	Seldom	Round	Crack Sugging Linear graben	Original shape Warp	Deepening Shape of mountain	
Stage II	Glide at bedding plain Slump as describe an arc						Large Separation scarp Slide scarp	Block	Type and magnitude of rainfall	Inner stress field distribution
Stage III	Fracturral slip Folding slide Debris slide						Minor scarp	Pressure ridge		relocation of water by micro landform
Stage IV	Flow type slide	Fluidic	Viscosty flow dominant	Small	Frequent	Long obal	Small scarp	Sightly hammocky wavey smooth		Trap

Fig. 5.13 Autonomous landslide destruction process and distinctive characteristics by landslide stages (after Miyagi, 1990).

accompany with the deformation of the shape, size, style of deformation, contribution of water, and the geophysical rock mechanism (Miyagi, 1992). **Fig.5.13** shows the framework of the processes of autonomous destruction. The initial movement forms a large square shaped landslide body. The body keeps the similar geological and geomorphologic features, though the body had received the deformation stress no doubt. A slight deformation will cause the next landslide. The next one might occur with a smaller and the materials deformed to the crushed one. This means that the water contribution must be strong and the weathering processes are also speed up.

6. Risk evaluation of landslide hazard by aerial photo interpretation

6.1 Changing process of landslide micro topography and the instability

The samples of risk evaluation are selected as follows;

(1) 20 cases of actual landslide hazard in Tohoku district.

(2) 130 cases of actual landslide and landslide topography at Iwate Prefecture in Tohoku district.

It has been required to find actually risky or active landslide topographies among a number of them and to take measures for them immediately. In this chapter, the internal structures of landslide will be observed closely and some ideas or ways to evaluate the systems of landslide activity and vulnerability of landslide areas will be displayed. Assuming a time axis of landslide phenomenon, it is possible to define the various stages of a sequence of landslide development; Primary stage, Active stage and periods of differentiation, expansion stage, suspension and dissolution stage etc.

The series of these stages is illustrated in **Fig.6.3**. The micro topography of the each stage reflects the characteristics of autonomous destruction processes (**Fig.5.13**).

(3) Each stage is made up of distinct micro landform units.

(4) Systematical interpretation and evaluation of micro landform units will make possible to capture a relative danger of landslides nearly automatically.

In the initial period of occurrence, a landslide has been gradually differentiated, become vulnerable and raised its coefficient of viscosity because some internal transformation in the body is weak and it is deformed again and again. But, it is possible to assume that such variability process proceeds intermittently and repeatedly in a geological time process. On the other hand, it has been repeatedly stated that so-called normal process, which could be distinguished from landslide deformation have continued. That is, at a landslide area, two types of geomorphologic process occur; one is an intermittent landslide action and the other is a normal processes (such as the formation of a talus, extension of erosive cliff, planation process such as gentle movement of the soil occurred by creep or weathering process). The land hazard risk evaluation is to distinguish these two processes, determine the stage of a landslide activity and interpret direct indexes of the risk. Based on these standpoints, we will show the variability process of the landslide topographies and the classification of the micro landform units as an index of them. Further, on the basis of this idea, the landslide hazard risk evaluation will be as follows.

(a) Landslide topography is identified and illustrated through aerial photo interpretation and development of the distribution map of landslide topography.

(b) Micro topographies are identified through photo interpretation and the items are checked on a card. The card is constructed on the system of item arrangement.

(c) The total score of the check items indicates the level of the risk. The score of items is estimated by AHP. Each landslide topography is identified special high risk as SA, high risk as A, moderate as B and low risk as C category (**Fig.7.7**).

(d) The high score landslide topography should be selected as a target of integrated inspection such as field investigation, monitoring of the moving condition and boring in case by case.

6.2 Meanings of the risk of landslide

Risk evaluation can be carried out by analyzing landslide topographies because most of the landslide processes, which actually cause natural disasters, result from the reactivity of aged landslide topographies. Risk evaluation will be based on the following assumptions.

6.2.1 Ideas of landslide hazard risk evaluation

(1) The fundamental factors for the evaluation are limited to topographical information interpreted from aerial photos.

(2) It should be considered that the scale or characteristics of interpretable landforms and landslide phenomena are often affected by the accuracy of aerial photographs.

(3) Other factors such as geological features or disaster's record, etc. are reference information in order to develop suitability of evaluation method, and then regarded as objects for the evaluation.

(4) The other factors such as rainfall are not objects for the evaluation.

6.2.2 Definition of landslide topography

(1) Landslide activity forms a characteristic "landform topography" distinct from any other landform units.

(2) The landslide topography in this report intends the most outer one (that is, an area which contains all of the micro landform units formed by landslide slip) among the areas which are divided topographically from the surrounding slopes formed by past landslide slips.

(3) Transformation of base rocks such as rock creep and sagging, etc. is mentioned as a phenomenon leading to a

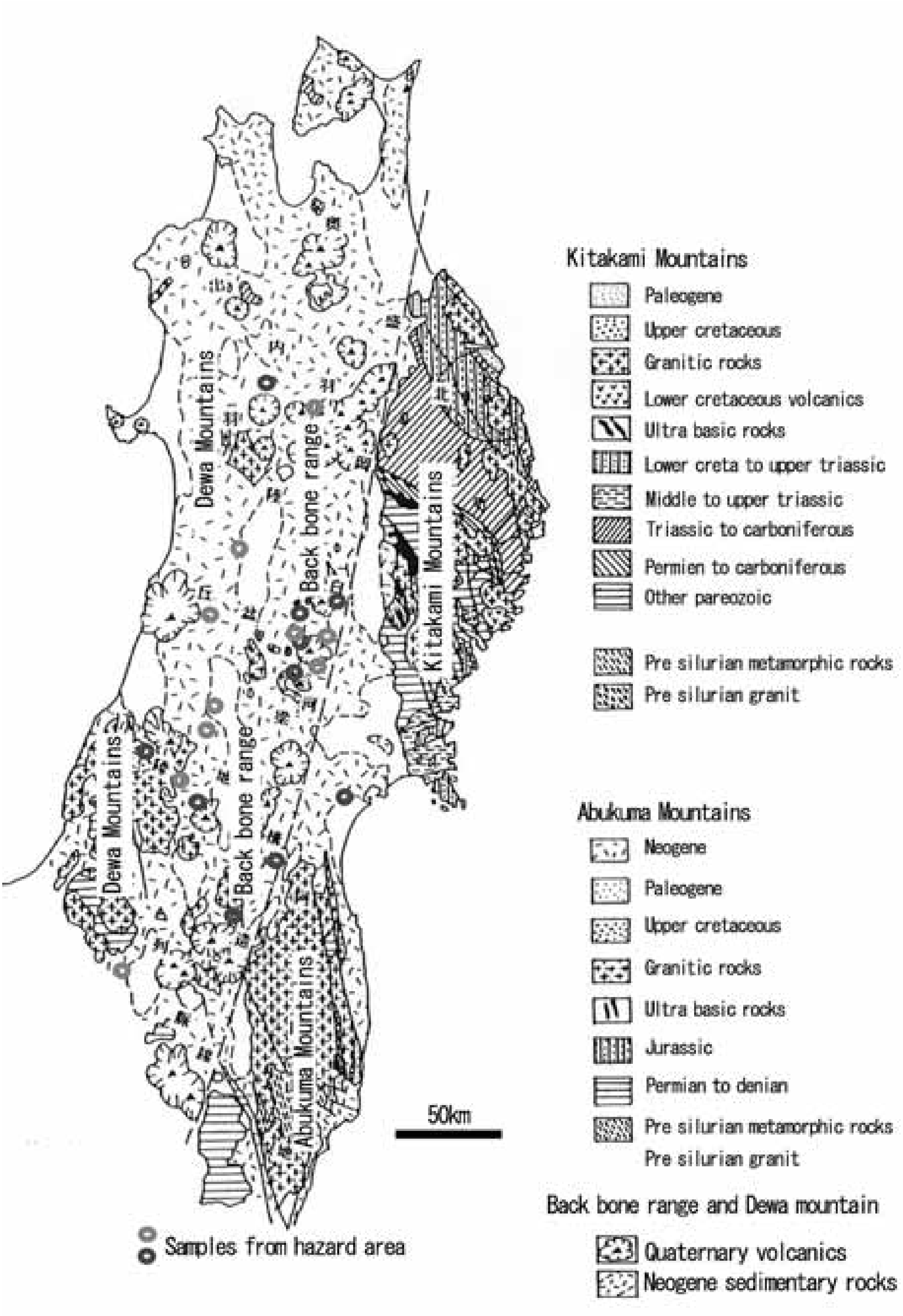


Fig. 6.1 20 cases of landslide hazard area where to application as a standard for the risk evaluation of landslide topography.

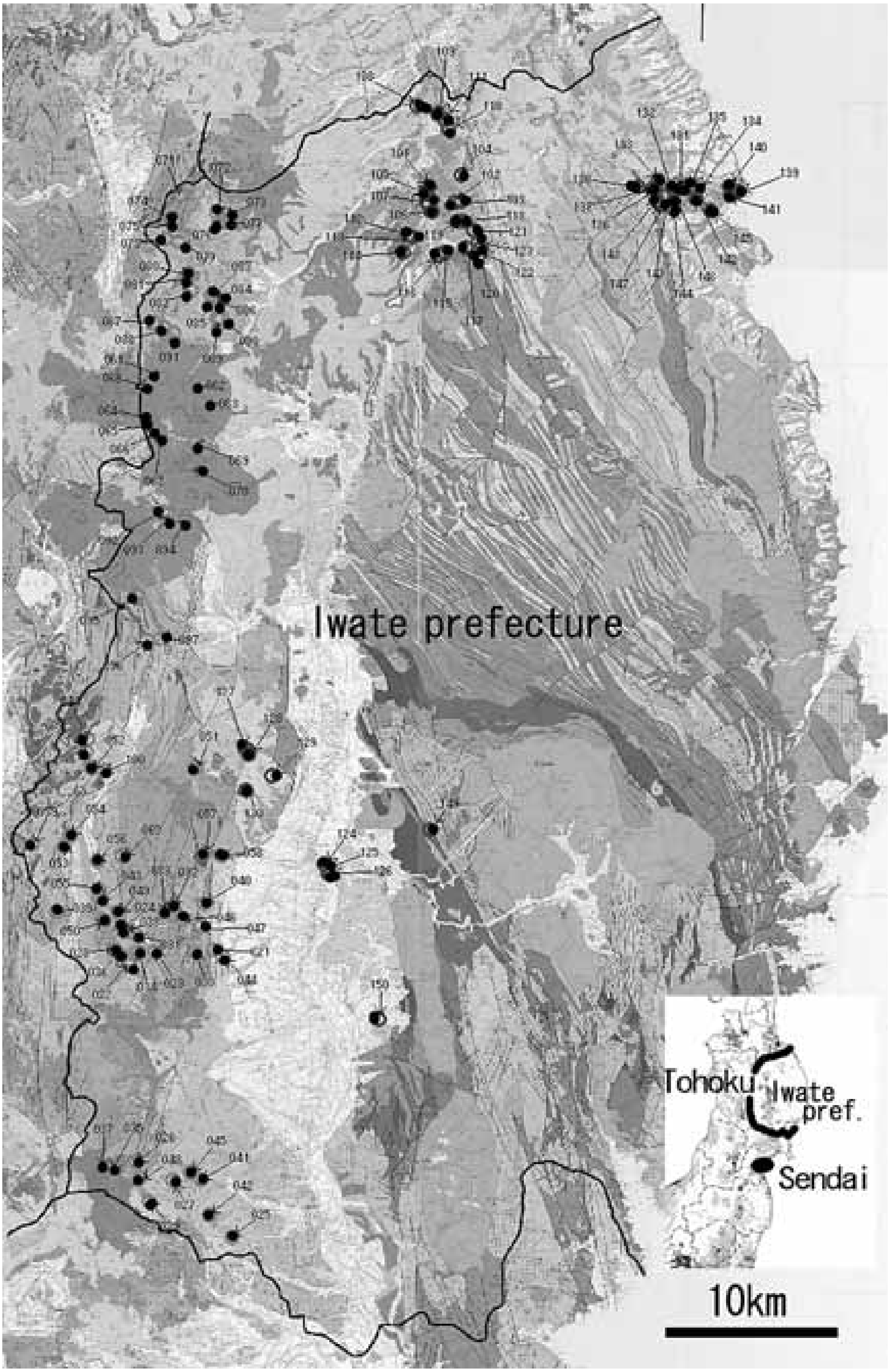


Fig. 6.2 130 cases of landslide topography for the risk evaluation of reoccurrence of landslide in Iwate Prefecture.

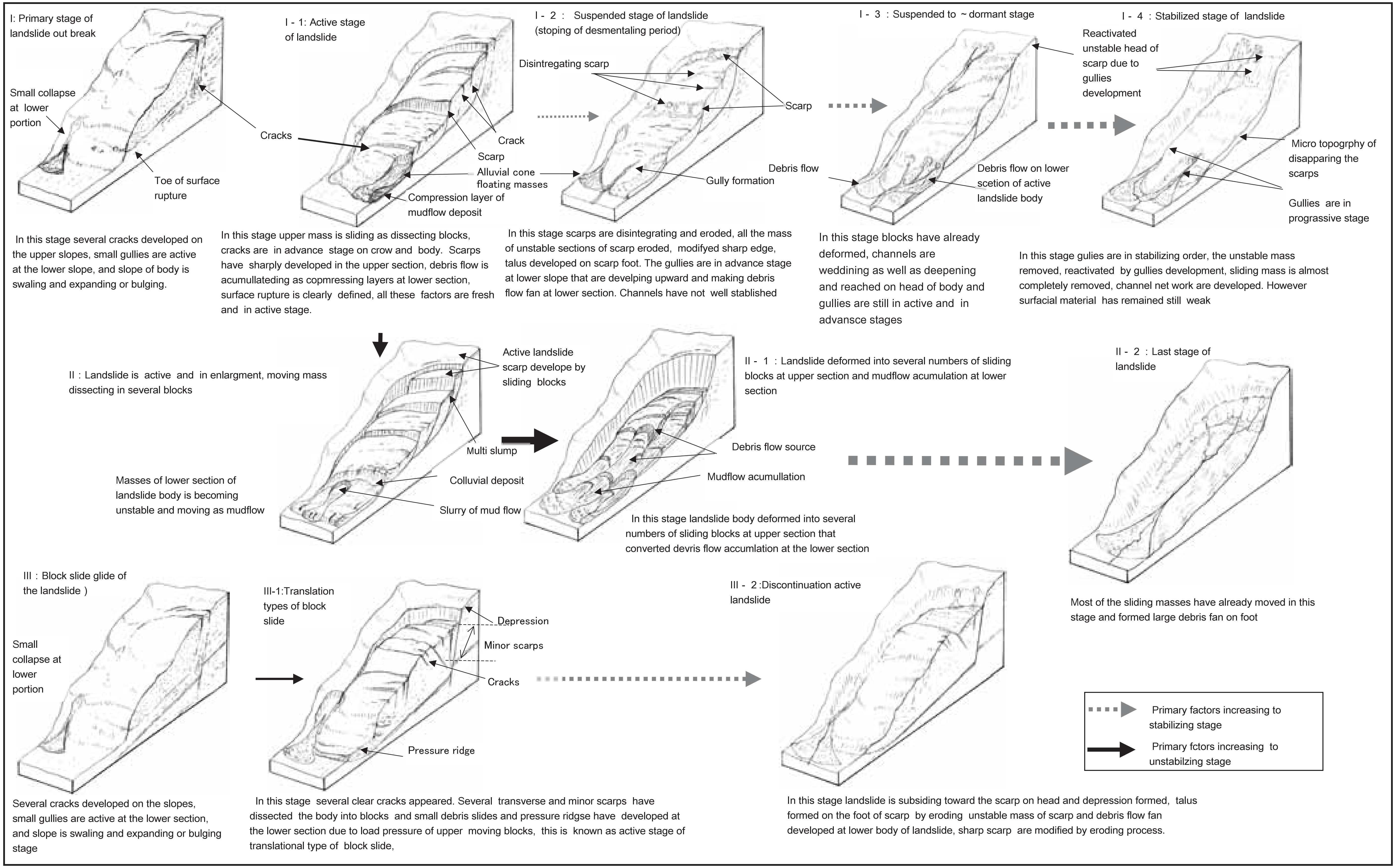


Fig. 6.3 A model of changing process of the outline and interior of landslide topography besed on the autonomous landslide destruction with the suspended stages (Iwate Prefecture, 2002, modified by Miyagi *et al*., 2003).

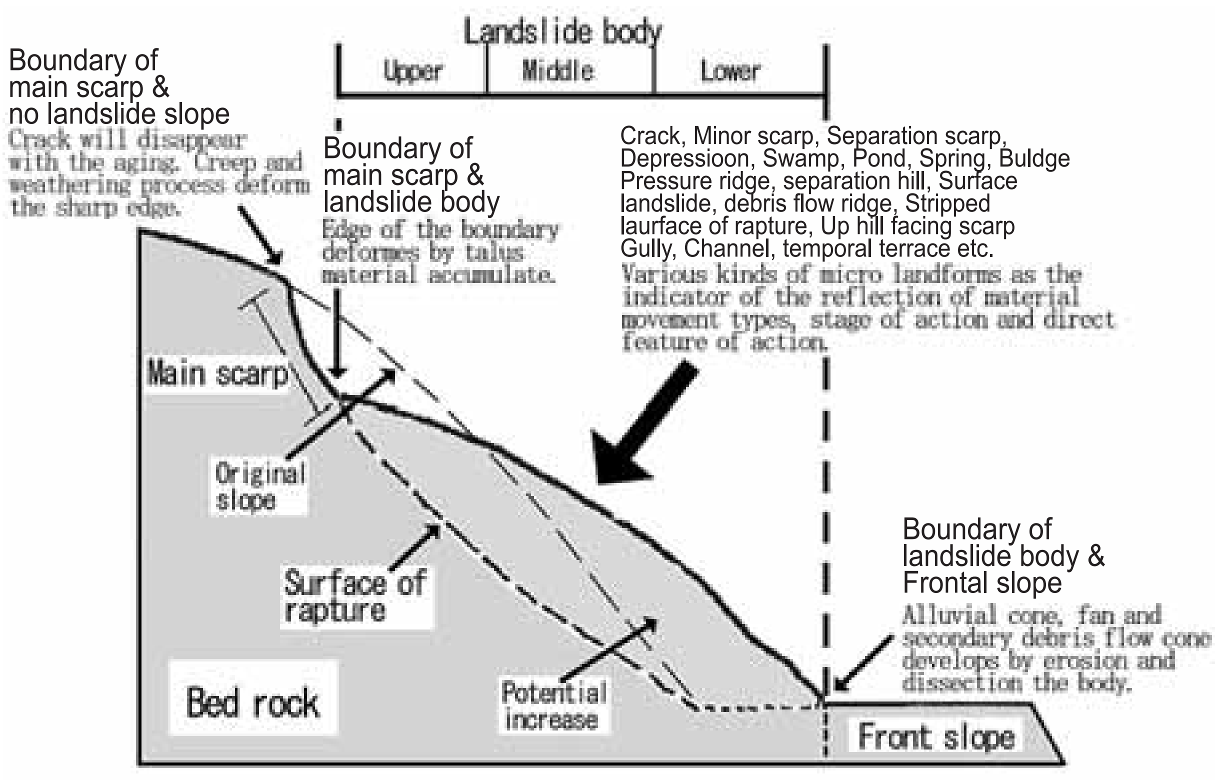


Fig. 6.4 Target features of for evaluation of landslide reoccurrence.

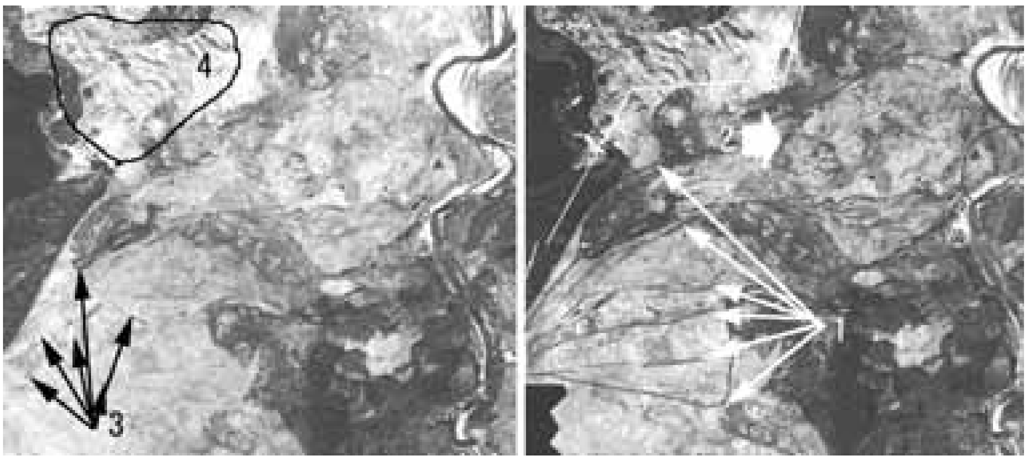


Fig. 6.6.a Flow mounds, small but sharp scarp and lateral ridge of clayey debris flow, pressure ridge. Weight value: 12.5. Such micro topographies characterize the clayey flow type landslide. The plan is long and oval, size is small and shallow, usually high water contains, very unstable. 1; Lateral ridges at the rims of the landslides. 2; Flow mounds distribute at the lower part of body. 3; Crown of landslides are connect to rims smoothly. 4; Lamina shape hammocky topography is called pressure ridge.

landslide or excluded from the objects for the risk evaluation.

6.2.3 Domain of interpretation

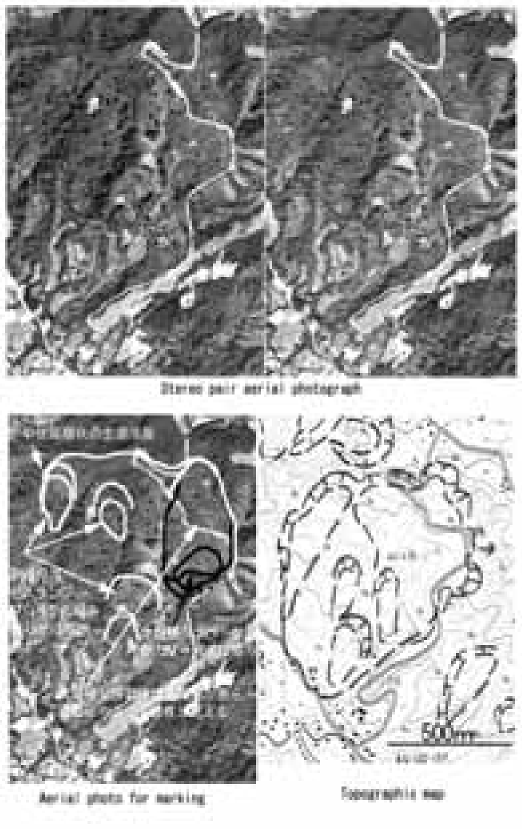
The domain of interpretation is basically the landslide topography defined in 6.2.1(2), its inner micro landform units and its surrounding area. Rock creep etc. should be taken into consideration but it is only for a reference. It will be difficult to judge their risk on the standard, which will be defined later.

6.2.4 Definition of landslide risk

The risk is a possibility of landslide phenomenon (including re-slips of landslides) which may occur somewhere in the landslide topographies defined in 6.2.1(2).

Stereo pair and facts of micro-landform features of landslide and basic landform interpretation
(Date of aerial photograph taken, Aerial photo No. ,
Scale 1 :)

(Name of Base map: Sheet No.)



Inspection record sheet for landslide risk evaluation

Major division	Main factor	Observation theme	Unstable factor: Large and unstable ⟷ Small and stable	Remarks: Scale	Remarks: Location	AHP Score
Micro landform features in the landslide body	Characteristics of active landslide	A: Types of movement	Flow mound Pressure ridge 12.1 .... Minor scarp 4.9 .... Separation scarp Depression trench 2.0			
		B: Level of clearness and micro landform components in the body	Huge no. of deformed blocks and clear micro topographic boundary 19.5 .... Clear micro-topography smooth boundary 12.5 .... Unclear deformed block 6.0 .... Smooth boundary 5.5			
		C: Level of stable	Head block separate from lower part 13.9 .... Gullies development 3.6 .... Linear erosion development 1.5			
		D: Direct features of movement	Cracks and scarlet 18.8 .... Tree crown deformation 6.3			
		Other minor features	(Causes: Swamped land, Pond , Deformed surface, Crack development, Changes ?)			
Level of after moving deformation at major boundaries	Age distribution	E: Top edge main scarp	3.8 Echelon → 3.2 Main scarp → 1.8 Creeping slope → 1.5 gully extension → 1.3 Modify to smooth slope			
		F: Boundary of the main scarp and the body	3.1 Non deposition → 1.8 Talus → 1.1 Large-scale talus → 0.6 Smoothly deformed by creeping and Talus development			
		G: Boundary of landslide body and the front slope	1.0 Non deformed landslide body → 0.5 Gully, Debris cone, → 0.4 Smooth surface → 0.3 Topography, Disappeared surfa			
Landslide body and adjacent environment	Geomorphic setting	H: Landslide body toe	8.6 Face to the undercut slope of river slope → 4.4 Face to the river → 1.6 On the flat plain → 0.9 Hit to opposite			
		I: Change of the potential of instability at lower half of body	19.2 Increasing → 9.2 Moderate the change of relief energy → 2.7 Decreasing			
Particularly removable deformed block in landslide			Yes ・ Non (Total No. small blocks)			
Un-describable matters	Unaffected landform of landslide					
			Total points of AHP assessment			No.
Risk of landslide based on your own experience			Large → Middle → Small	Score by own inspector		No
Comment and view of each section				Reference No.	Name of Map	

Fig. 6.5 Inspection record sheet for the risk evaluation (The check items and the scores are based on the discussion by engineer inspectors. The process of the decision of the item weight value is according to the AHP, which explained on chapter 7).

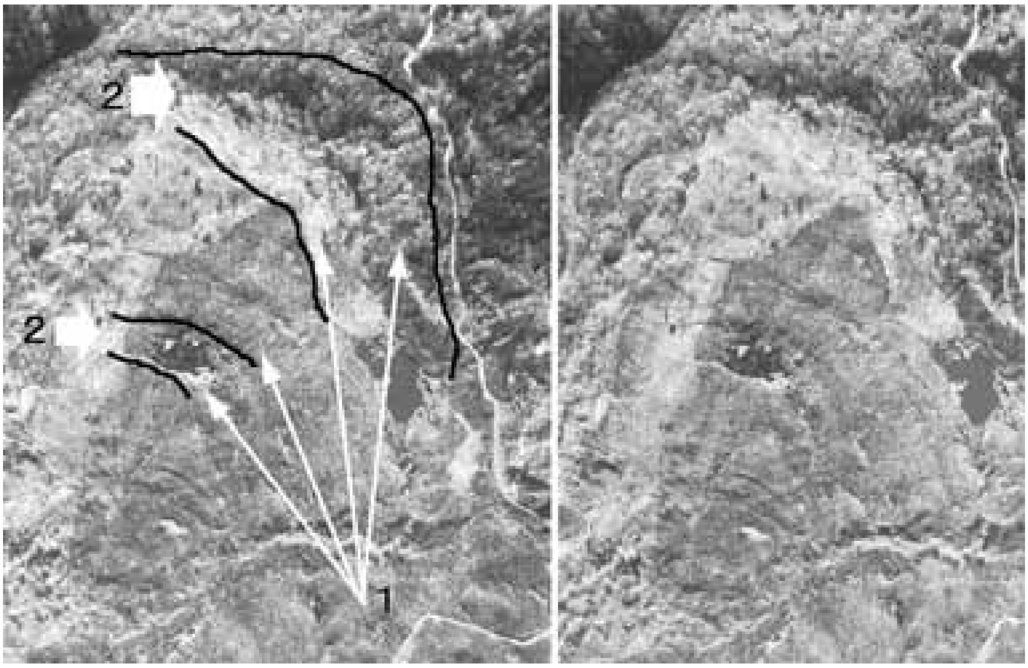


Fig. 6.6.b Minor scarp. Weight value: 4.9.
Minor scarps are typical feature of rotational slump type destruction. 1; Sharp main scarp 2; Minor scarps develop in front of the main scarp.

Fig. 6.6.c Separation scarp. Weight value: 2.0.
Separation scarp are typical feature of the glide type, spreading type landslide. It makes a graben or trench depression between the facing scarps. 1; Separation scarps. 2; Trench.

Wherever a landslide occurs, the unit of risk evaluation should be the whole area of the landslide topography. However, if the phenomenon is local, that is, an unstable area is narrow and it is not contained in the group of the landslide body, this definition may not be applied.

The following points should be noticed.

(1) The occurrences of landslide caused by artificial influences such as man-made alternation are not objects to the evaluation since they are largely affected by geological factors.

(2) The risk is a possibility of landslide occurrence, not risk evaluation about the magnitude of occurrence or behavior of

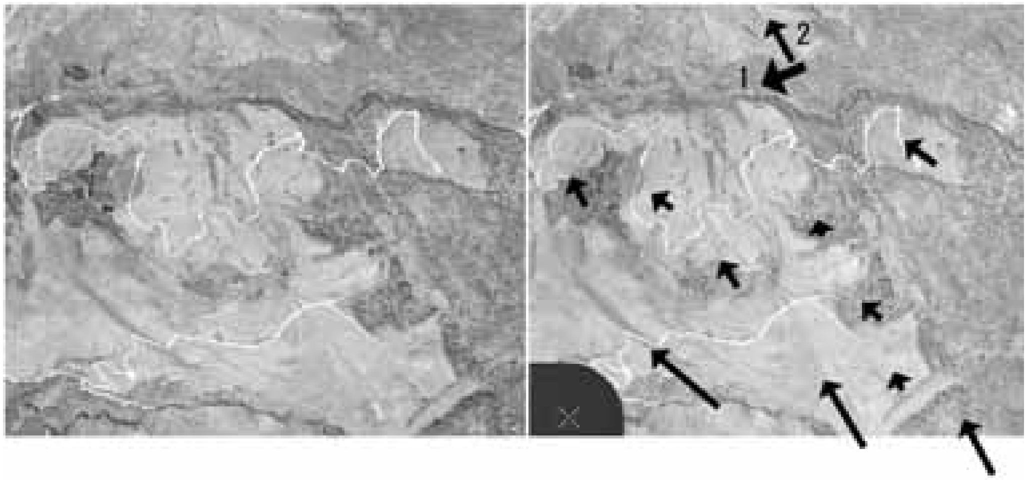


Fig. 6.6.d Complex of the pull a part structure (long arrows) develops minor separation cliff and trench by tensional force. The separated block is differentiated to smaller sub blocks by rotational slump landslide. The photo shows two directions (arrow 1 and 2) of forces.

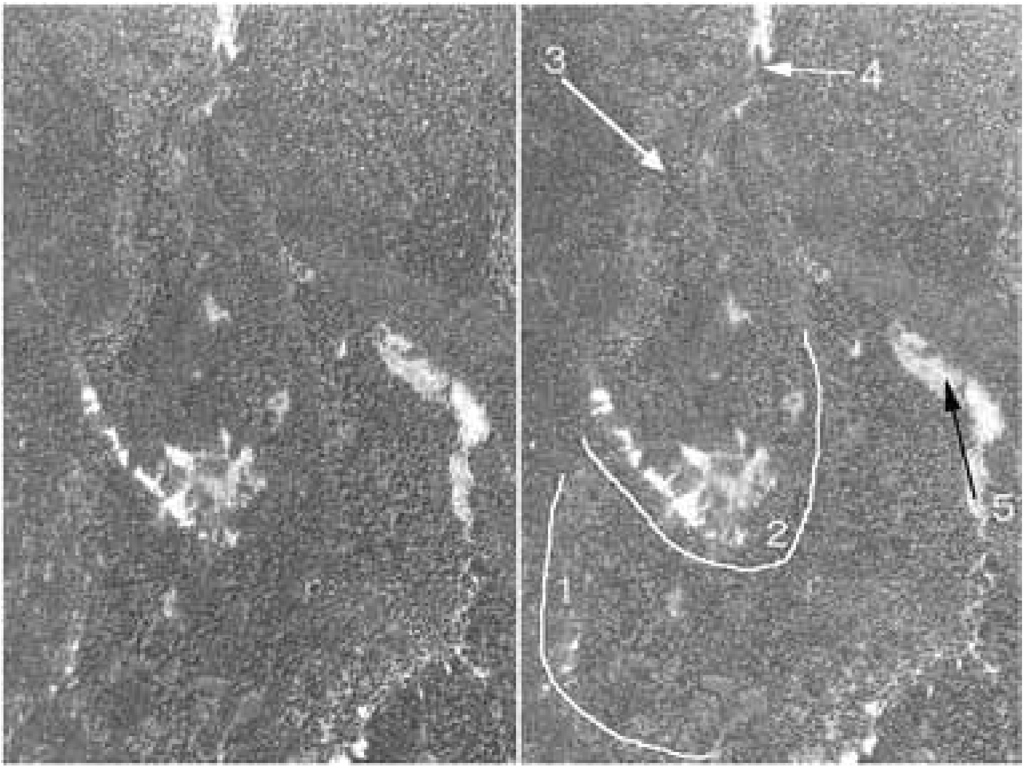


Fig. 6.6.e Landslide establish the secondary movement such as debris avalanche, debris flow etc. 1; Old main scarp. 2; Minor but new scarp. 3; A part of the body collapsed and moved into the river. 4; Toe part of the debris flow. 5; Landslide body dam the river and develop a swamp.

destruction on the surrounding area in movement.

(3) If the whole area of a landslide topography is evaluated based on an unstable area within it, an interpretation map should represent the area and mention the existence of such area, its position within the landslide topography and relative relation to others, etc.

6.3 The assumptions on landslide hazard risk evaluation

(1) On natural slopes, geomorphologic processes such as weathering, erosion, and sediment etc. have regularly occurred.

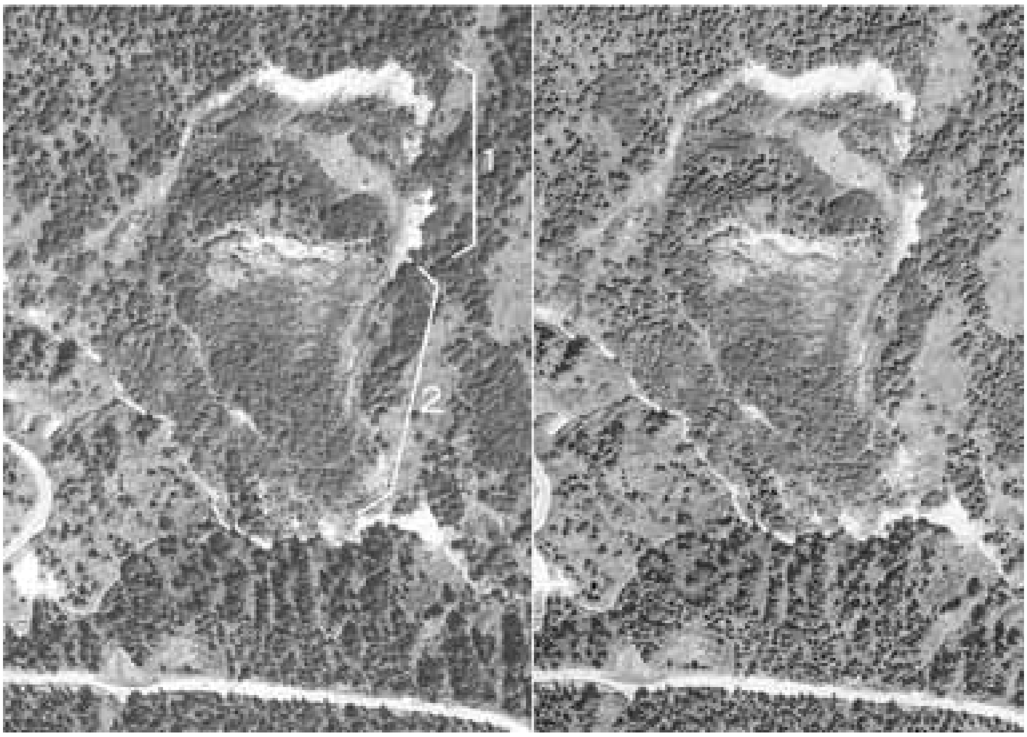


Fig. 6.6.f Landslide body easy to separate to several blocks by minor scarps. 1; Consists of large blocks. 2; The feature of debris flow appears as the lamina like surface.

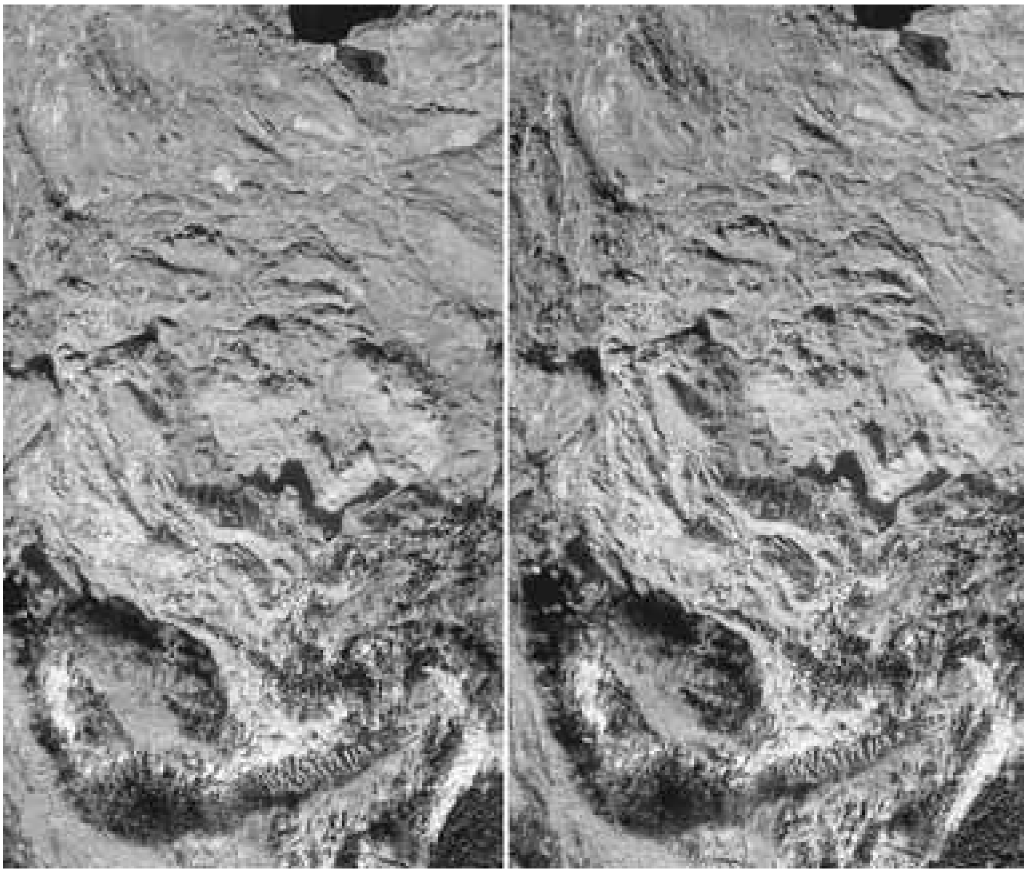


Fig. 6.7.a Huge number of deformed blocks and clear micro topography. Weight value: 19.5. The number of micro topography in the body which is an indicator of the extent of destruction.

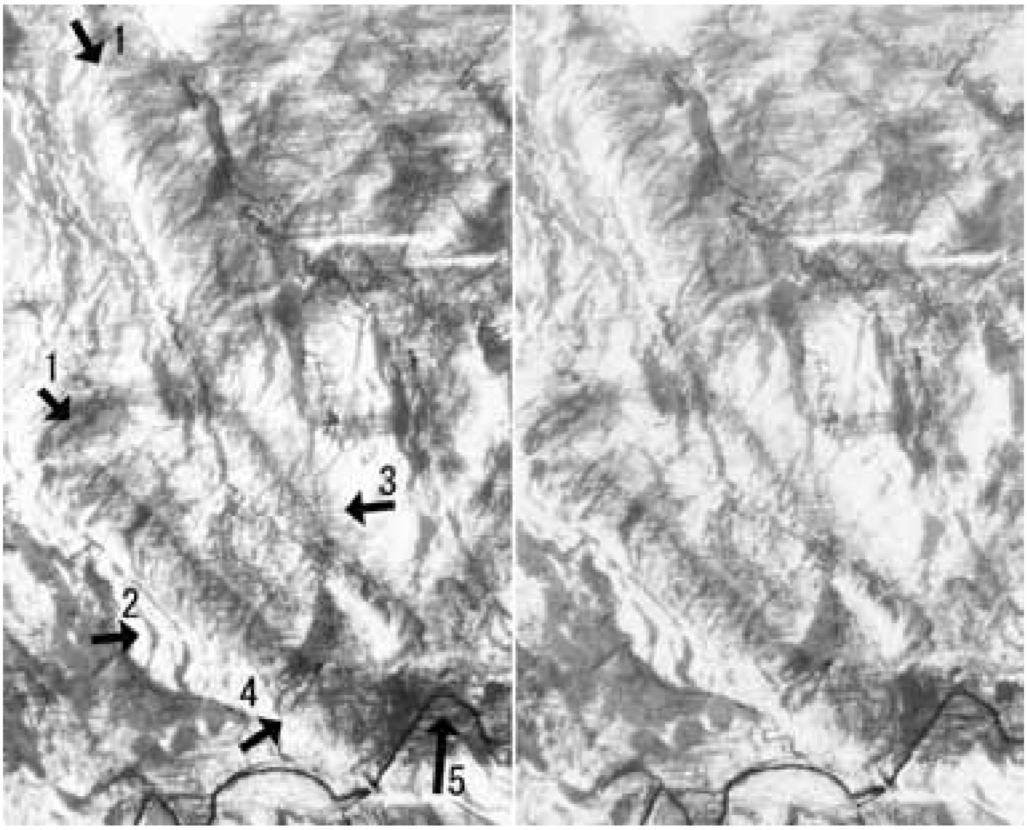


Fig. 6.7.b Huge number of deformed blocks and clear micro topography. Weight value: 19.5. A number of parallel and small scarps are the feature of the destruction. The number and clearness its self means the high activity. 1; Parallel minor scarps. 2; The parallel scarp deforms the direction to the downward with the release of compression force. 3; Large landslide block (between 1 and 3) moved to down ward but the toe is shuttered by adjacent blocks. 4; Toe part face to the river which deformed the stream to south (down) ward by sharp sliding block. 5; Toe slope attacked by stream will become slope failure and small landslide occur.

Landslide phenomenon occurs intermittently and suddenly. Actual landslide topography is composed of the combination of landslide and normal process discussed above. These two geomorphologic phenomena can be distinguished through aerial photo interpretation.

(2) The clearer a landslide is, the higher the possibility of landslide occurrence increases. That is, if a landslide occurs in the near past, the recurrence of it will distinctively increase compared with that of more aged landslides.

Thus it will be necessary to compare the scale of the above two geomorphologic phenomena and investigate the time process after the landslide activity.

(3) As a landslide body has acted again and again, it would be gradually degraded and the material changes to clayey, increasing its recurrence.

Thus a part of micro landform unit, which makes up the body shows the own geo-physical feature.

(4) It is impossible to evaluate a landslide located in where no landslide occurs, or an initial landslide topography which have lost the most part of landslide scarp and the landslide body. A geomorphologic approach to risk evaluation is to capture the above properties (2), (3) and (4) by interpreting the aerial photographs.

(5) If we interpret the items listed below and mention them in the card, it will be possible to evaluate the possibility of the land hazards just enough.

6.4 Check items of landslide hazard risk evaluation

In order to proceed the understanding, several maps are handed in; **Fig.6.3** is a schematic drawing of remarkable micro landforms, that is, an index of variability process of landslide topography. **Fig.6.4** is a schematic cross profile as identification items. We designed the inspection record sheet for the systematic and objective risk evaluation (**Fig.6.5**). The observation theme A to I will explain.

6.4.1 Major classification

(1) Micro landform in the landslide body (an index concerned with the characteristics of the types of movement, material, critical feature of action, etc.)

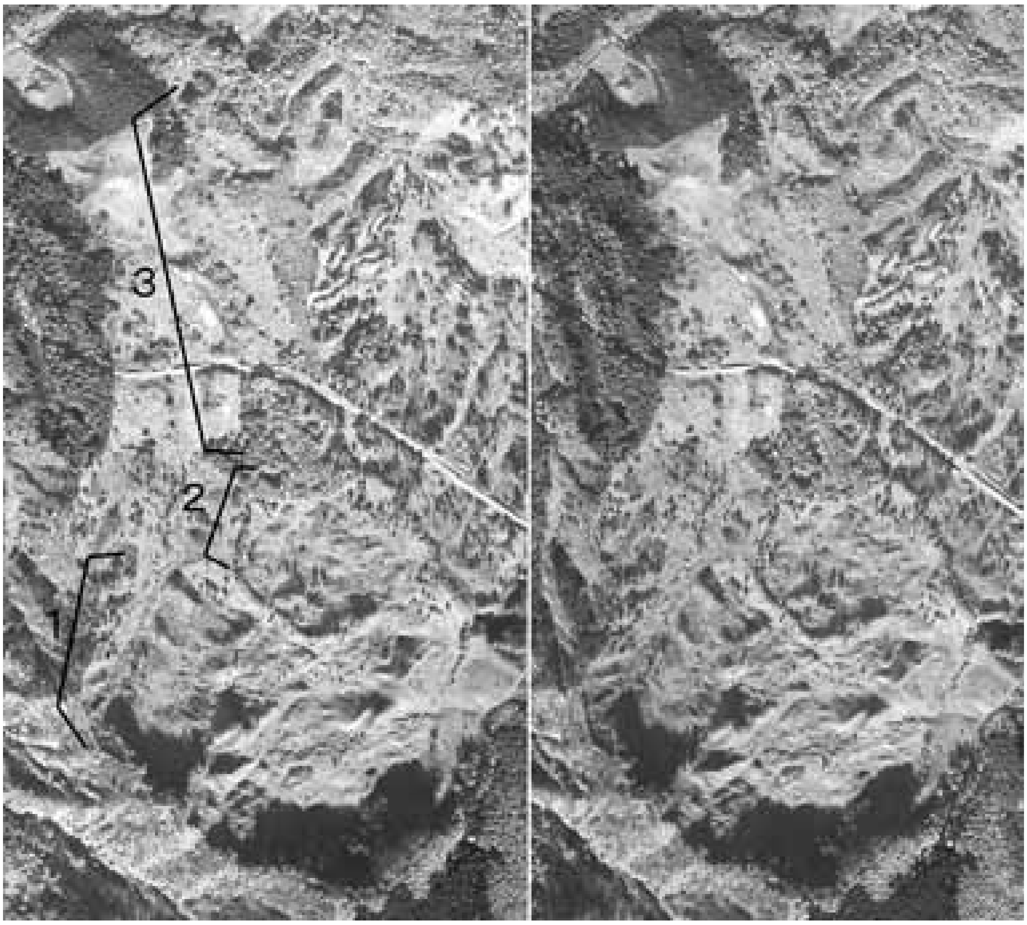


Fig. 6.7.c Clear to unclear micro topography and the boundary. Weight value of the clear micro topography and smooth boundary: 12.5. Weight value of the unclear deformed block: 6.0.

1; Is also an example as same as **Fig.6.7.a** & **Fig.6.7.b**. 2; Micro topography of the part is slightly deformed and thus the boundary of the blocks change to smooth. 3; The landslide feature mostly diminish. Unclear micro topography and smooth boundary is almost same value as the indicator of the suspended stage.

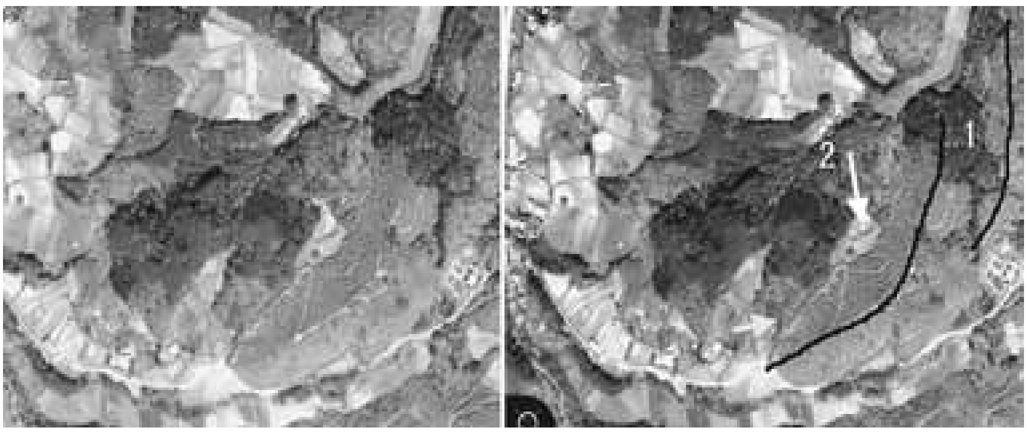


Fig. 6.7.d Smooth boundary. Weight value: 5.5.

Micro topography by the landslide action will diminish by the normal geomorphic process while the suspended stage of landslide development. The small micro topography is easy to diminish and the boundary of the blocks changes to smooth by talus and weathering the original shapes. 1; Edge of minor scarp modified by weathering. 2; Boundary of the minor scarp and sub block is modified by talus material accumulation.

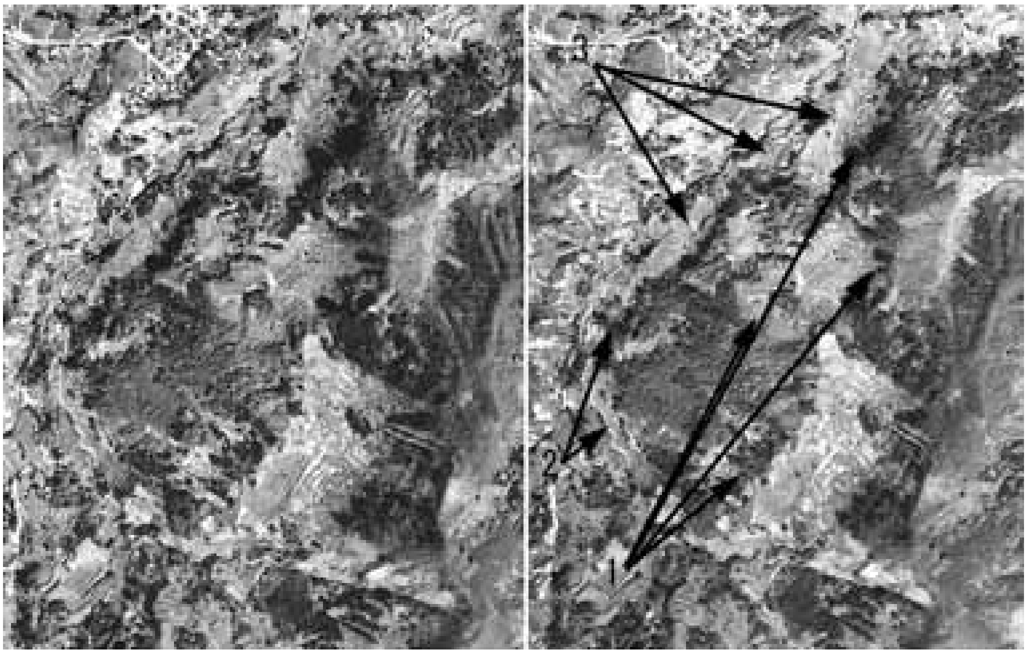


Fig. 6.8.a Head block separation from the lower part. Weight value: 13.9.
Front part of the body received the number of landslide action, thus the material crushed and deformed from the consolidated one to weathered clayey one. The instability increases especially in a front part of the body. This is a typical process of autonomous destruction process. Small scale landslide and slope failure, flow type shallow landslide getting frequently. This photo shows a part of large scale landslide topography. 1; Minor scarps. 2 and 3; Small landslides occur at the toe part of the blocks.

Fig. 6.8.b Gullies development. Weight value: 3.6.
The normal erosion processes will appear at the suspended stage. Gully erosion is one of the clear and easy to interpretational features. 1; Lateral erosion by stream cut the toe part of the body. 2; Gullies start the dissection to the toe part of body.

Various types of micro landforms and their spatial arrangement that indicate the activities of landslides mainly distribute within the domain of the landslide body.

(2) Boundary of the landslide topography (an index of aging factor)

The clearness of the top edge of main scarp and the sharpness between the lower end of the main scarp and the landslide body are obvious indicators of the time process after the last landslide.

(3) Landslide body and its geomorphic setting

These are factors having effects on the potential energy of the slip body caused by the last action.

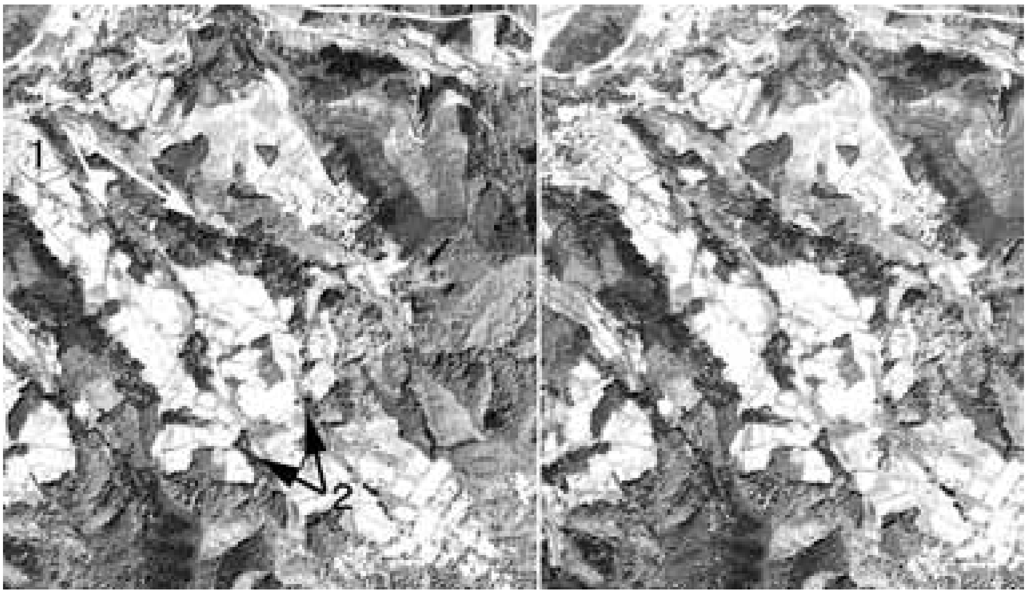


Fig. 6.8.c Linear erosion development. Weight value: 1.5
Gully will change to channel by the suspended stage continue long time. 1; Two small river dissected the body widely. 2; Upper stream intrude near the boundary of the body and main scarp.

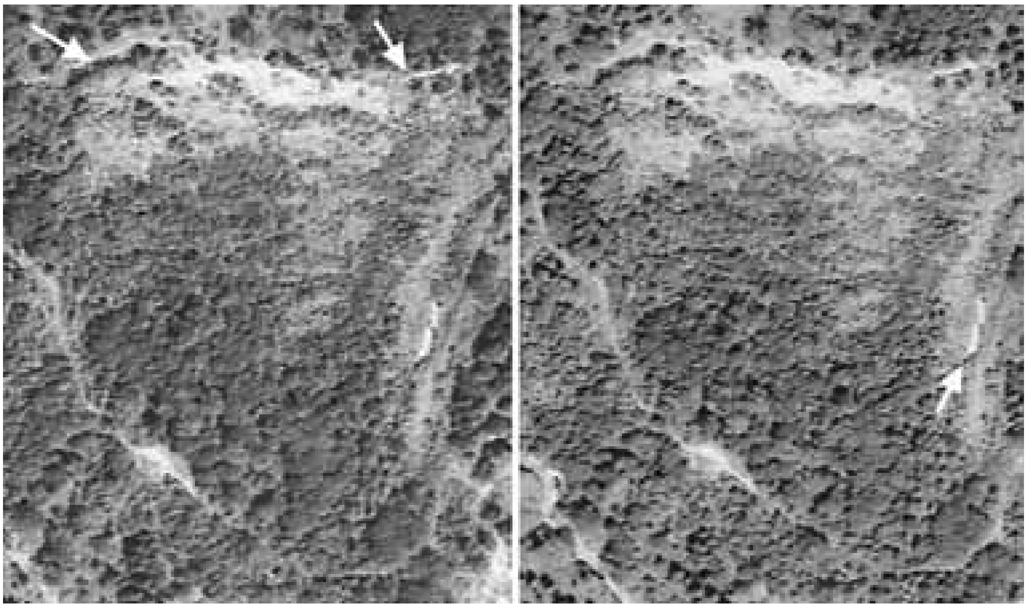


Fig. 6.9.a Crack and scar. Weight value: 18.8.
Cracks and some scars are direct indicators of the landslide action. Arrows in figure are typical cracks in a very active landslide.

The landslide action could change the instability of the landslide body, increasing or decreasing their geomorphic setting such as the body face to attack slope of the river.

6.4.2 Sub classification

(1) Micro landform in the landslide body

A) Type of movement (Fig.6.6)

Micro topographies such as flow mound, pressure ridge which caused by mud flow, debris flow or so called clayey debris flow to mud flow type landslide are fairly unstable because the strongly weathered clayey materials will increase the recurrence of landslides (**Fig.6.3.I.1, II.1, Fig.6.6.a**). Various types of landforms such as block glide or block slide develops graven or trench and facing separation cliffs through the process of lateral spreading (**Fig.6.3.III.1, 2, Fig.6.6.b**). Generally, their potential of the reoccurrence is judged as small compared with the former. The minor scarps

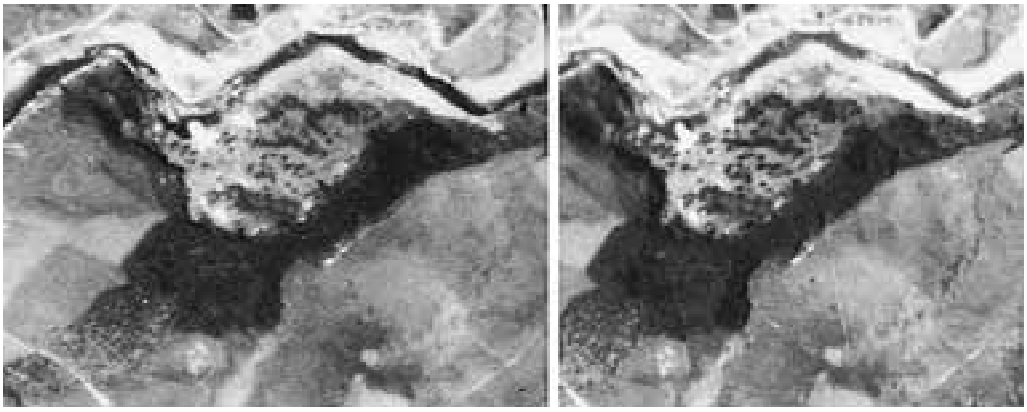


Fig. 6.9.b Tree crown deformation. Weight value: 6.3.
Crack is very important feature but sometimes it is difficult to identify trough photo interpretation. The deformation of the forest canopy is a indirect sign of crack. Although, such deformation appears by artificial land deformation too. By the reason the score is much poor.

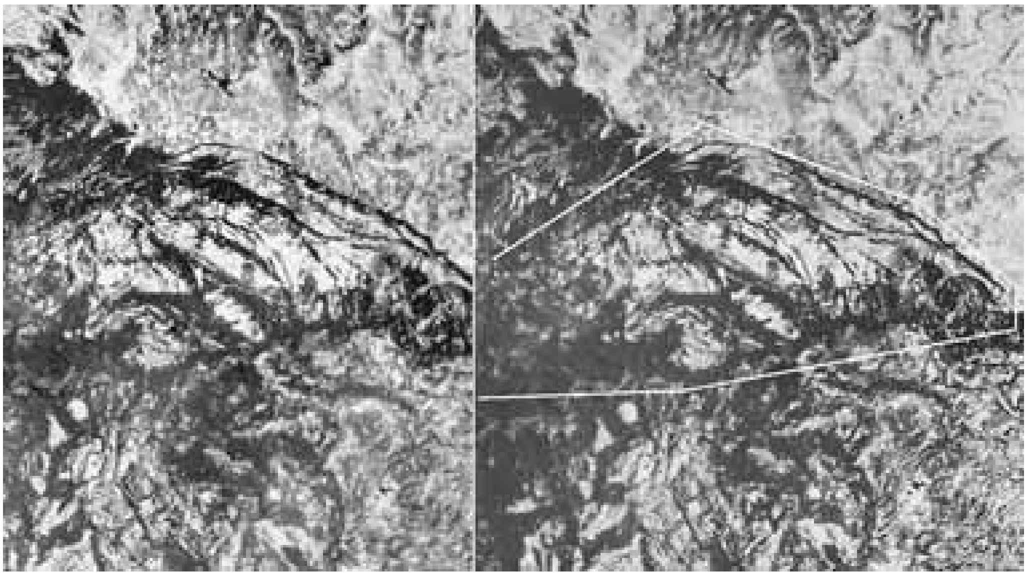


Fig. 6.9.c Typical crack and minor scarp.
Crack is caused by tension force. The force of scarps has various processes. The identification of the two kinds micro topography is usually very difficult specially in case of the small minor scarp. So, we combine the two micro topographies as one term of crack.

seem to indicate relatively advanced stages of autonomous destruction which locates in the middle of those (**Fig.6.3.I.1, II, Fig.6.6.c**). **Fig.6.6.d,e** and **f** is the typical features of movement types.

B) Level of clearness and micro landform components in the body (Fig.6.7)

As so many years have passed by, micro landform units within the landslide body (cracks, minor scarps, graven and depressions, pressure ridges and burdges) have been modified and lost their original shapes by suffering regular weathering and erosive process (**Fig.6.3.I.3, 4, Fig.6.7**). In general, landslide body is divided into small parts changing toward the active stage (**Fig.6.3.II, II.1**). The density of micro landforms indicates some kind of the level of destruction and the level of material modification (**Fig.6.7 a, b, c and d**).

C) Stability of the landslide body (Fig.6.8)

Landslide body often becomes unstable by suffering the head block separation from lower part and small failure at the toe and lateral portion. Such inversion phenomenon often become a trigger of the reoccurrence the large slide (**Fig.6.3.I, I.1,III.1, Fig.6.8.a**). On the other hand, if the

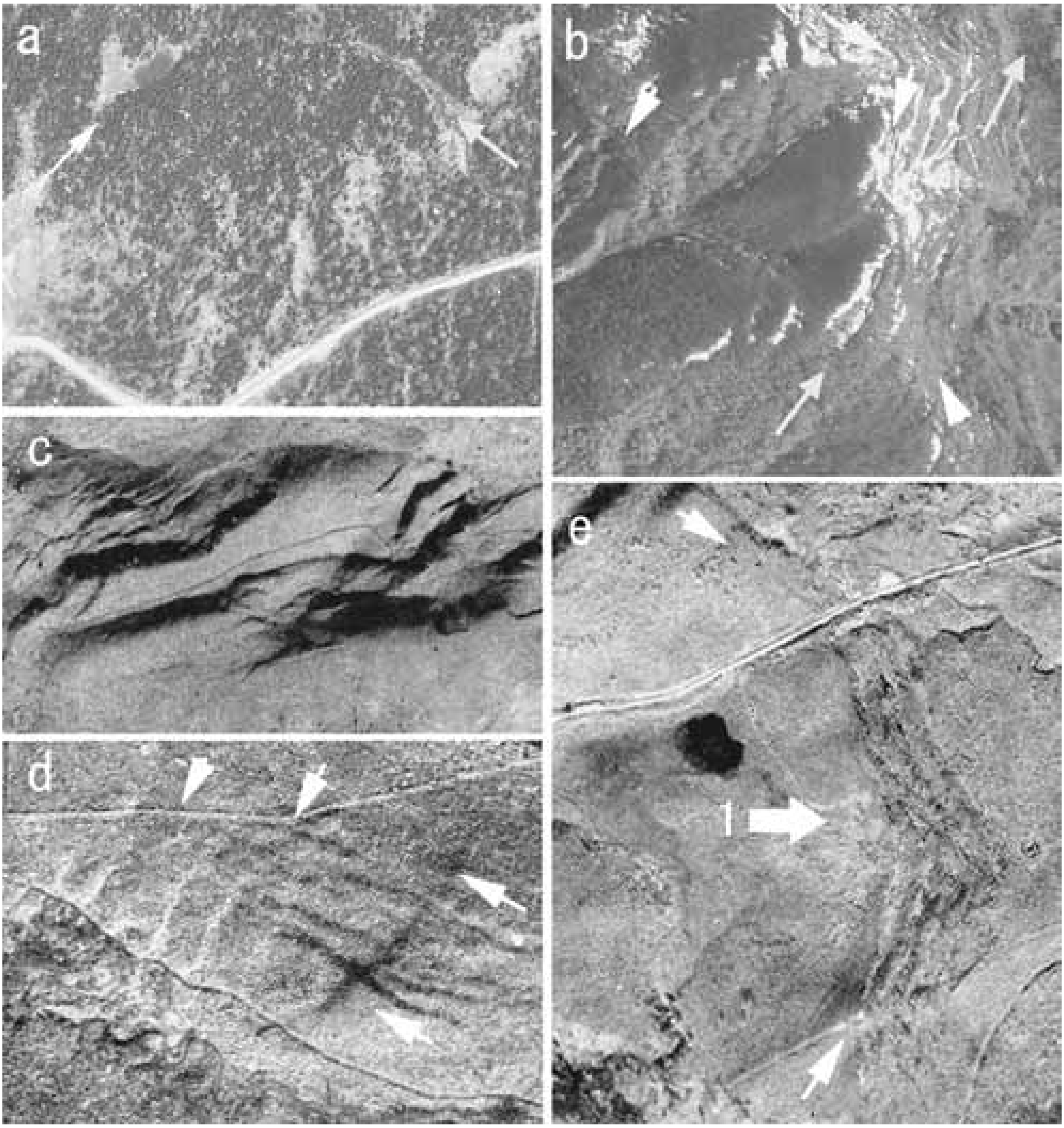


Fig. 6.9.d There are various kinds of cracks in the body.
a; Large simple crack between the two arrows. b; Parallel cracks caused by lateral spreading and subsidence of crest of mountain. c; Cracks by landslide brock collapse. d; Conjugative cracks by two direction. e; Small and parallel cliffs developed by over thrust by landslide action.

landslide faces to the suspended stage, the process that causes the invasion of gullies and erosive valleys can be thought as an erosive process leading to its disappearance (**Fig.6.3.I.2,3,4, II.2, Fig.6.8.b, c**).

D) Direct features of movement (Fig.6.9)

Generally, if a crack is clear, it is allowed to think that little time have passed after the occurrence of landslides or landslides may occur in the future (**Fig.6.9.a**). Based on photographs, it is often difficult to recognize the existence of cracks. However, crack is often recognized as an indirect feature like a systematic deformation of the forest crown. It should be noticed that the crown deformation may be some paths though the forest or they be formed by deformation of the ground (**Fig.6.9.b**). Thus, it will be appropriate to assume

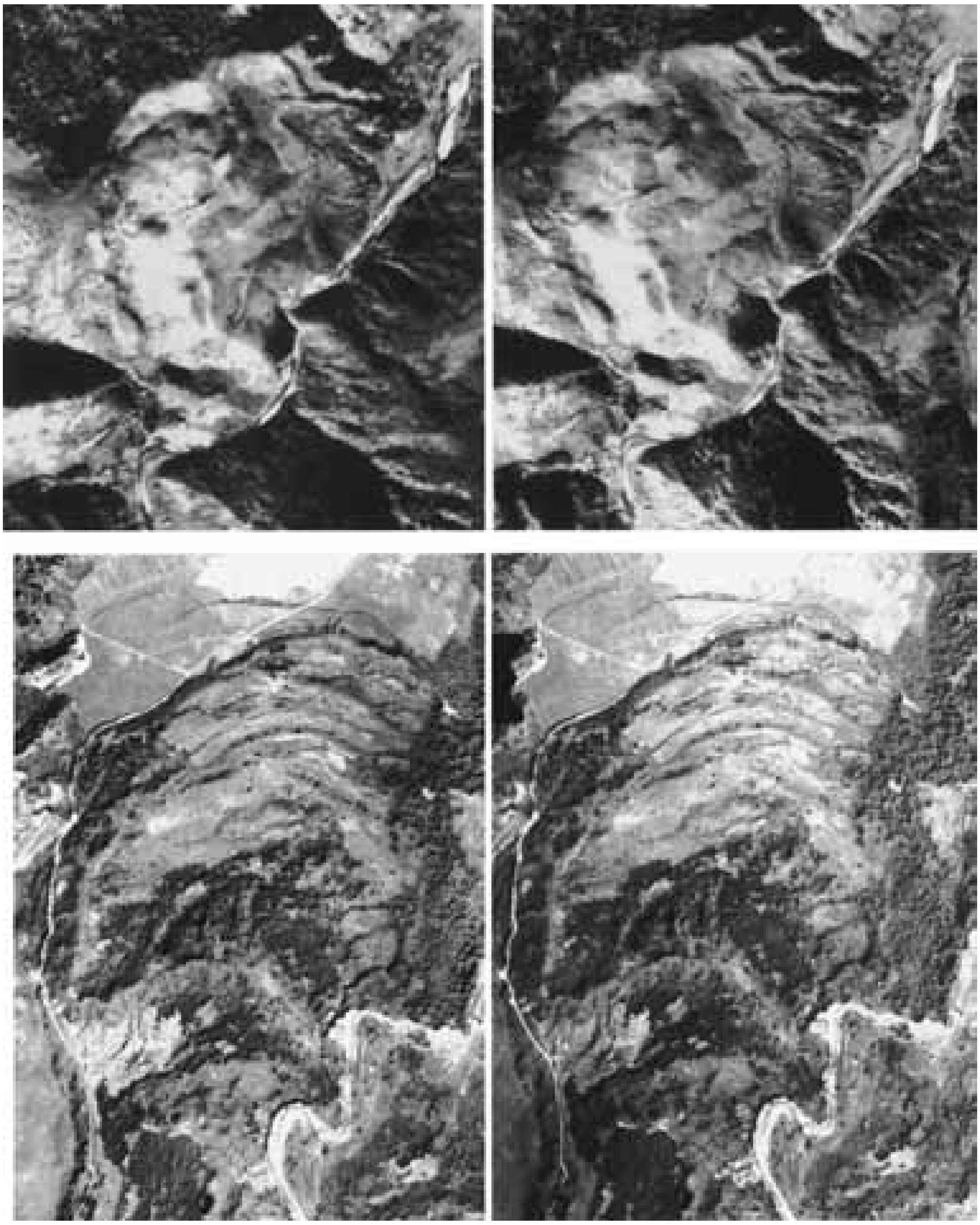


Fig. 6.10.a Major boundary of landslide.
These two landslides are very recently moved. The major boundary such as top edge of main scarp, boundary of main scarp and landslide body keep the original topographic features.
Above 1; Top edge of main scarp. 2; Boundary of main scarp and the body. 3; Boundary of the body and frontal slope.
Below 1; Top edge of main scarp. 2; Boundary of main scarp and the body.
Weight value in this case, the edge of main scarp is 3.2 (above) and 3.8 (below), The boundary of main scarp and the body is 3.1 each.

that crack is arranged as a distinctive unstable factor of movement and the deformation of forest crown is arranged as a little unstable factor.

Although cracks and minor landslide scarps distribute, no clear topographic difference is found through the photo interpretation. Thus, the minor scarp should include the cracks in its evaluation system. **Fig.6.9.c**, **d** shows the various kinds of cracks and minor scarps.

(2) Level of deformation after landslide action at major boundaries

Fig. 6.10.b Major boundary of landslide.
This is the case of suspended landslide. There is talus topography (1) developed between the main scarp and the body. The weight value is 1.8.

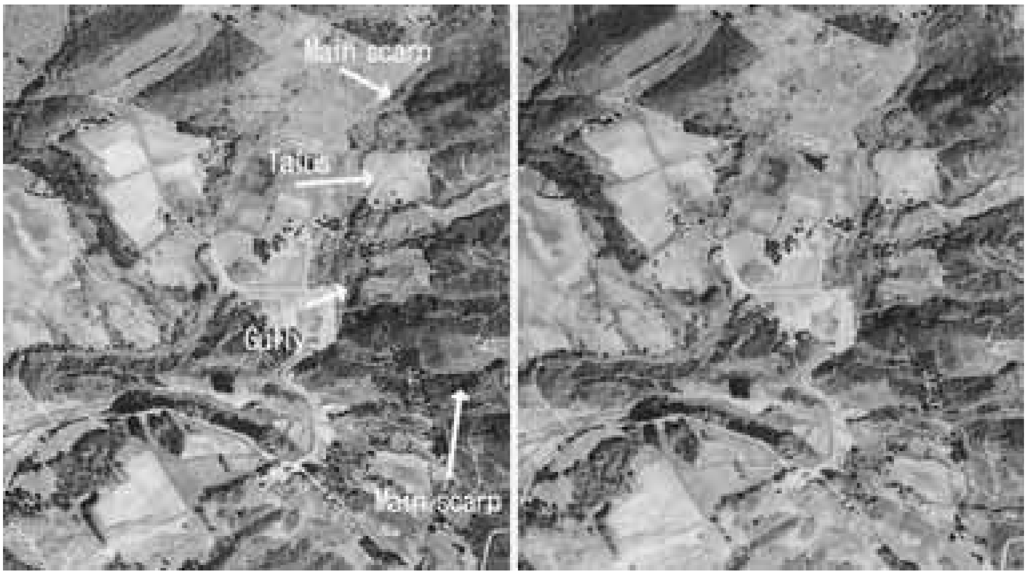


Fig. 6.10.c Major boundary of landslide.
The boundary of landslide body and the frontal portion. The toe part is modified by creeping and there is no clear surface landslide and/or slump topography. Gully is also developing.

After a landslide activity, as many years have passed, a landslide topography gradually have become stable by suffering regular weathering and erosive processes. This phenomenon can be fully observed in the landslide boundaries or around them. Here, we will pay attention to the location of three boundaries, (a)-(b), and evaluate how the conditions of the relevant landform have changed after landslides had occurred at each boundary. In card, unstable items, which have not passed so long time are always arranged in the left and those that are more aged are arranged in the right.

E) Boundary of landslide main scarp and upper normal slope (Fig.6.10)

The top edge of a mains scarp after the action that have lateral stress free situation there remain some unstable materials. Thus, a number of echelon cracks and lateral cracks develop at the top edge of main scarp (**Fig.6.10.a**). After the action, the stability increases gradually and is modified by creep. Furthermore, weathering process deforms the initial topography and decreases the sharpness of edge. If it holds the suspending condition so long time, the area of creep and gully erosion will be finally developed.

The typical topographic characteristics of the landslide main scarp will disappear (**Fig.6.10.d**).

F) Boundary of main scarp and landslide body (Fig.6.10)

This is a very clear boundary like an edge of the main scarp, which is formed just after the action. A plenty of materials fall down from the scarp and accumulates at the

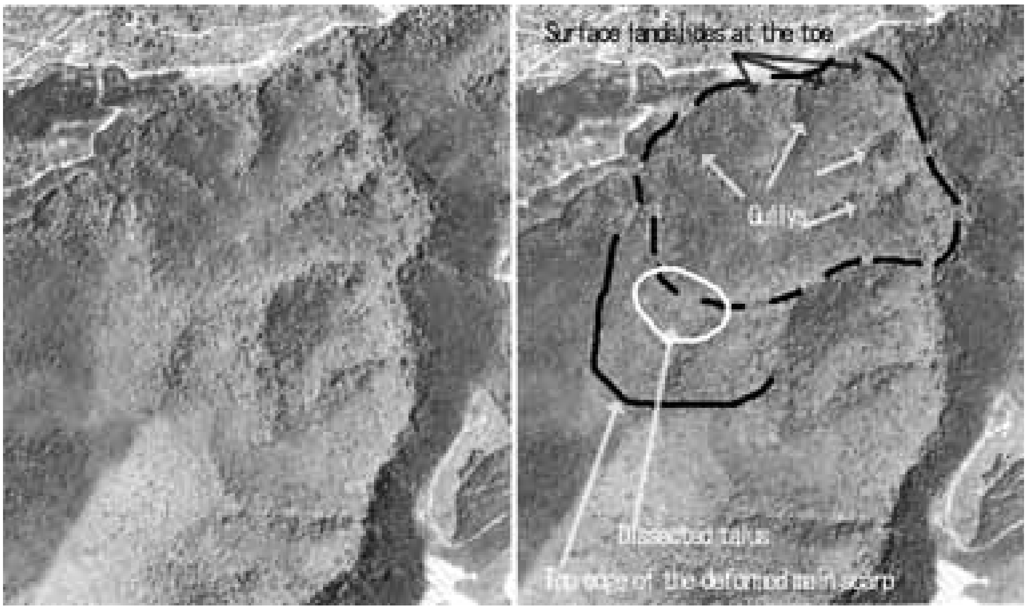


Fig. 6.10.d Major boundary of landslide.
This photo is the typical non active landslide topography. The major landform of landslide still remain but all of the major boundaries are smoothly modified by talus accumulation and weathering, The body dissected mostly by gullies.
The weight value of the top edge of main scarp is 1.3, boundary of main scarp and the body is 0.6, boundary of landslide body and the frontal slope is 0.3.

Fig. 6.11.a Landslide body and adjacent environment. Landslide body at lower face to the other near. Increase toward the active condition. Weight value: 8.6.
Landslide body face to the undercutting slope of river stream has very high potential of landslide.

boundary. Such materials develop talus topography. The development of talus accompanies with the aging. Spatial ratio of the talus is an indicator of the time process after the event (**Fig.6.10.b, d**).

G) Boundary of stable slope and landslide body (Fig.6.10)

This boundary is also very clear after the action. The landslide body is deformed and dissected by weathering process and linier erosion such as gully erosion (**Fig.6.10.c, d**). It leads the development of gully, channel at the body and small alluvial cones develop in front of the landslide body. So, such components of micro landforms are also an indicator of time process after the landslide action.

(3) Landslide body and its geomorphic setting (Fig. 6.11)

There are factors which promote the instability of the landslides contain erosion at the toe part or at the lower part of landslide body and the increase of relief energy etc.

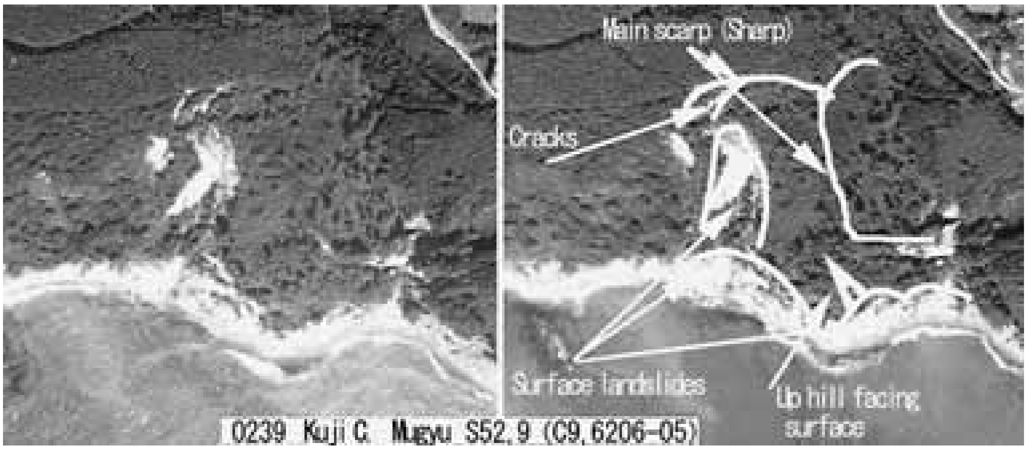


Fig. 6.11.b Landslide body and adjacent environment. Landslide body at lower face to the other near. Increase toward the active condition. Weight value: 8.6.
Landslide body face to coast is also very unstable because of the coastal erosion by wave and coastal sea current.

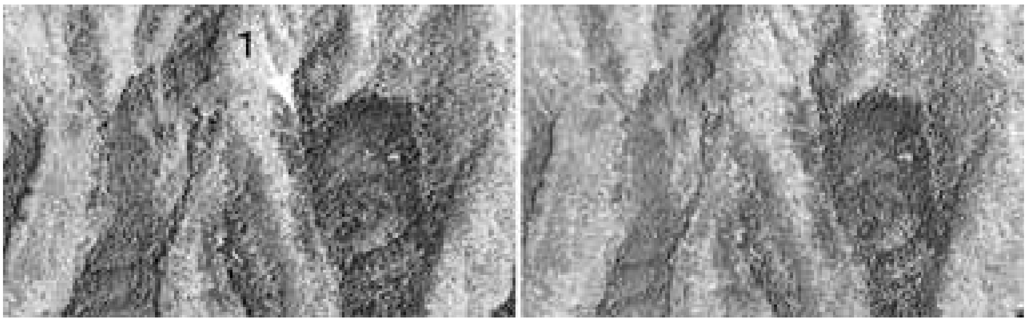


Fig. 6.11.c Landslide body and adjacent environment. Landslide body at lower face to the other near. Decreasing (stabilizing order). Weight value: 0.9.
The landslide body moved but if it stop by any barrier the potential of reoccurrence should be decrease.

Focusing on these geomorphic setting will enable to predict the prospective transition of stability.

H) Toe part of the landslide body (Fig.6.11)

If it is a mountain stream such as in erosion situation, it will be identified as equal to attack face to river. But notice that the front part of a body may become unstable by the part abutment to the opposite bank of the mountain stream.

I) Lower part of the landslide body

An increase or decrease of relief energy will lead the change of the potential of the landslide body.

＊ Although we can recognize multiple items in a landslide body, we have to mark only one item at each category box. In such case we should mark those items as much unstable ones.

6.4.3 Name and definition of micro landform items

The items of a micro landform, which will be used in the risk evaluation, are defined as follows. Some attention in photo interpretation is mentioned, too.

(1) Surface landslide, slope failure and scar

Definition: A landform that is formed by exfoliation and fall of soil layer. The soil layer is categorized into A, B and C horizon. The thickness of the moving layer is usually less than 1 meter. The body easy easily collapses, diffuses and accumulates at the foot of the slope. It often occurs on a part of the landslide body or main scarp of the large scale landslide. This includes quite small slump type landslide.

(2) Crack

Definition: A crack that is formed by the force of tension stress which occurs within the landslide body. But the crack is not different from the minor scarp and thrusting edge. We will identify the crack as a kind of such minor scarps.

＊ At the top of photograph, the line can be seen as a sharp scratch on the land surface.

(3) Minor landslide scarp

Definition: A scarp which topographically followed by slides, which occur in the collapse processes within the landslide body.

＊ There are some geomorphologic relations of landslide scarp, which develops within the landslide body. Minor landslide scarp should be distinguished from the separation scarp.

(4) Separation scarp and trench

Definition: The scarp formed by tensional force occurred within the landslide body. The topography causes the relative depression that lies between the two parallel facing scarps. The depression in this case will expose the landslide slip surface of it.

＊ Separation scarp and trench are steep cliff which sometimes analogues to minor scarps. But they can be definitely distinguished as the set of facing scarps from the minor scarp.

(5) Presser ridge and bulge

Definition: These are formed by the differences of the spatial distribution of the stress force and the spatial differences of the velocity of movement in the landslide body. The presser ridge has a direction of right angle to the landslide direction.

＊ This exhibits a small thrust (including under thrust) movement, too.

(6) Flow mound, debris flow ridge

Definition: These are formed when a part of the landslide body is changed to the strongly weathered or debris clayey conditions with full water. The flow mound usually locates at the toe part of the body and the debris of flow ridge locates at the lateral fringe of the body.

＊ In many cases, at the top of photograph, they are identified as a gentle hummocky relief having no clear direction. However, in movement such as flow, minor horse shoe shape scarplet which develops on the upper parts of its area are small and their body shape in plan is often long and oval.

(7) Swamp, pond and depression

Definition: a blocked relatively lower portion or autonomously developed depression such as sink hole makes swamp and pond. Such depression is very common in the landslide body because of the rugged topography. Relatively large depression occurs at the boundary between the landslide body and main scarp.

＊ It is easy to identify them since they are quite characteristic micro landforms. But in terms of an indicator of landslide, these items are little important.

(8) Gully, dissection channel

Definition: Ravine topography which was formed by non landslide processes, for example, fluvial erosion process at a part of the landslide body. Although the dissection process occasionally increase the instability and functions as a trigger of next action, such topography can be identified as an indicator item of suspended condition of landslide activity.

＊ These micro landforms can be distinguished from others such as cracks or trench in that the formers are running along rivers. However, if gullies or erosive channels are small or their occurrence positions are hard to recognize, it may be difficult to distinguish them.

Other micro landforms: Erosive surface, Springs, Sagging and Block streams, etc. are mentioned if they are identified.

7. Evaluation of the probability of landslide occurrence by AHP based on the results of aerial-photo interpretation

7.1 Introduction (outline of the evaluation work)

For the purpose of establishing the evaluation of the probability of landslide occurrence interpreted by aerial-photographs, we researched at Tohoku district, in particular, Iwate Prefecture, Northeastern Japan, as a model district, based on AHP. As mentioned in earlier report (Konno and Miyagi, 2003), this research was implemented through seven times discussions at working group and six times evaluation committees over a period of two years. At the working groups, 8 core inspection engineers with great store of experience about landslides met together and researched the 150 cases at Tohoku district (**Fig.6.1, 2**) through brain storming. In particular, at the working group discussions, all of the members agreed the methodology of risk evaluation based on the practice of interpretation and card marking, and thus supposed a way to develop a rational and objective quantitative approach.

Also, as a result of the application of this method to cases of landslide occurrence at the Tohoku region, it was inspected that this method is almost appropriate. In this paper, we will introduce not only the process of agreement based on the new notion "degree of agreement" but also card marking and the coefficient of each item, which actually put

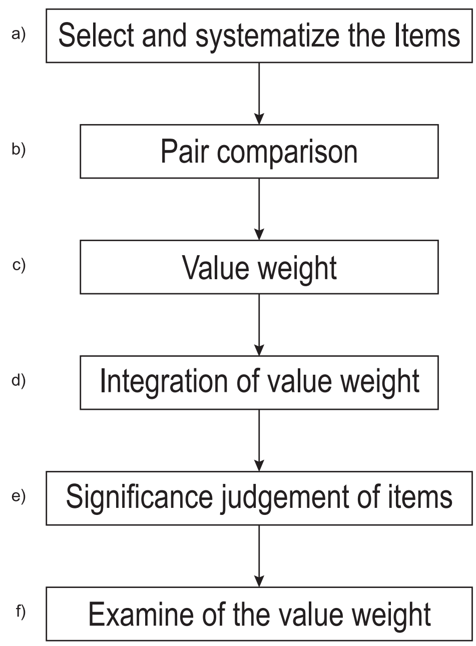


Fig. 7.1 Step of the AHP evaluation.

	Major types		Sub categories	Details	Weightage value	Remarks
Risk evaluation of micro landform of landslide	Micro landform features in the landslide body	A	Type of movement	1 Flow mound and pressure ridge	12.5	
				2 Minor scarp	4.9	
				3 Separation scarp, Depression, trenches	2	
		B	Level of clearness and micro landform components in the body	1 Huge no of deformed blocks and clear micro topography	19.5	
				2 Clear micro-topography of smooth boundary	12.5	
				3 Unclear deformed block	6	
				4 Smooth boundary	5.5	
		C	Level of stable	1 Head block separation from the lower part	13.9	
				2 Gullies development	3.6	
				3 Linear erosion development	1.5	
		D	Direct features of movement	1 Cracks and scares	18.8	
				2 Tree crown deformation	6.3	
	Level of after moving deformation at major boundaries of landslide	E	Top edge of main scarp	1 Echelon	3.8	
				2 Main scarp	3.2	
				3 Creeping slope	1.8	
				4 Gullies extension	1.5	
				5 Modified to smooth slope	1.3	
		F	Boundary of the main	1 Non deposition	3.1	
				2 Talus	1.8	
				3 Large scale talus	1.1	
				4 smoothly deformed by creeping and	0.6	
		G	Boundary of landslide body and front slope	1 Non deformed landslide body	1	
				2 Gully, debris cone	0.5	
	Landslide body and adjacent environment (Geomorphic setting)			3 Smooth surface topography	0.4	
				4 Disappeared surface	0.3	
		H	Landslide body toe	1 Face to the undercatting slope of river	8.6	
				2 Face to the river	4.4	
				3 On the flat plain	1.6	
				4 Hit to the oppsit slope	0.9	
		I	Landslide body at lower face to the other near course	1 Increasing toward the active condition	19.2	
				2 moderate the change of relief energy	9.2	
				3 Decreasing	2.7	

Fig. 7.2 Weight value of each items of risk evaluation.

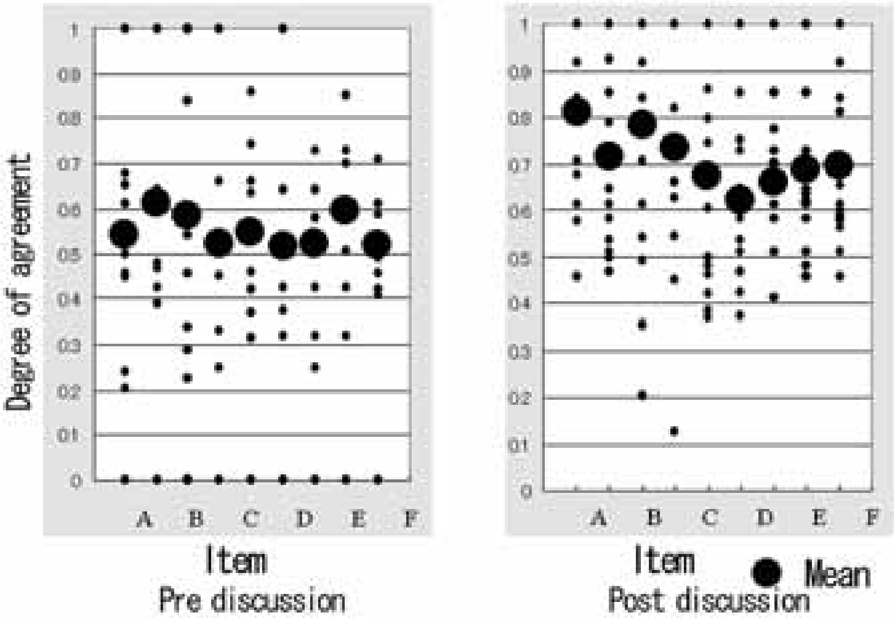


Fig. 7.3 The before and after the degree of agreement by inspectors' discussion.

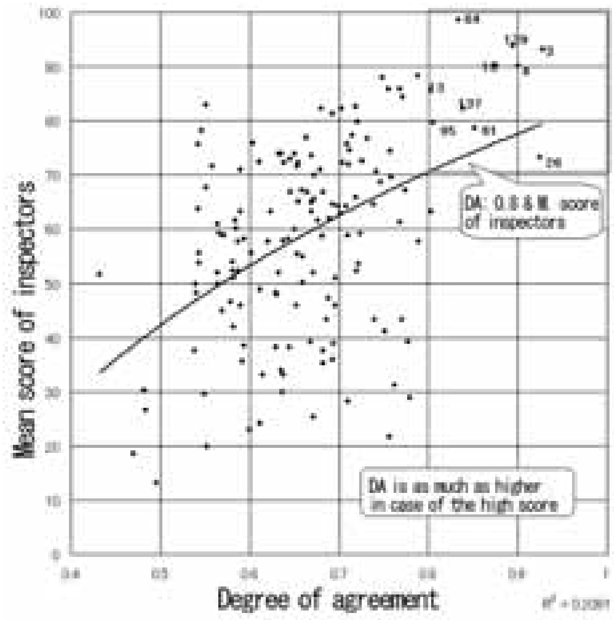


Fig. 7.4 Relationship between the degree of agreement and the mean of card score of evaluated landslide.

into practice.

7.2 Analysis

7.2.1 AHP（Analytic Hierarchy Process）

This, proposed by T.L.Saaty, Pittsburgh Univ. US. is a method in order to measure the relative influence between the items. The items concerned with decision are classified hierarchically and the weight of each item is determined by comparison a pair of items with some elements on the same level. Furthermore, generalizing the values makes possible to recognize the comprehensive importance (or propriety). AHP has the following characteristics; 1) it is possible to compare some opposing ideas or elements based on a different standard since the evaluation of each item depends on the subjective standard. 2) the evaluation is easy to made since a pair of items are compared and the importance of all items can be obtained as a result of the evaluation. 3) it is possible to compare with other ideas since AHP is a quantified method. 4) it is possible to confirm the influence of an item to the structure and the conformity of judgement. **Fig.7.1** shows the basic process of the AHP.

7.2.2 Determination of evaluation standard and its hierarchy

We interpret the evaluation standard concerned with the probability of landslide occurrence and hierarchize it as **Fig.7.2**. First, some items, as basic ones to the evaluation of the probability of landslide occurrence, were classed as the following three categories. The large classification contains (I) The micro landforms of the landslide body as an item of the characteristics of movement, (II) The boundary of major landslide landform component as an item of the time process, (III) The landslide topography and the adjoining environment as in index of geomorphic setting. They each have the medium classifications of 8 categories; A: manner of movement, B: degree of sharpness C: degree of instability of landslide body, D: probability of direct feature of landslide action E: Between the top edge of main scarp and the upper slope F: Between the main scarp and the body, G: Between the landslide body and the frontal slope, H: The toe part of landslide body, I: The lower part of landslide body. The items of the medium classifications further divided into small categories, which are check indexes in the card. Each

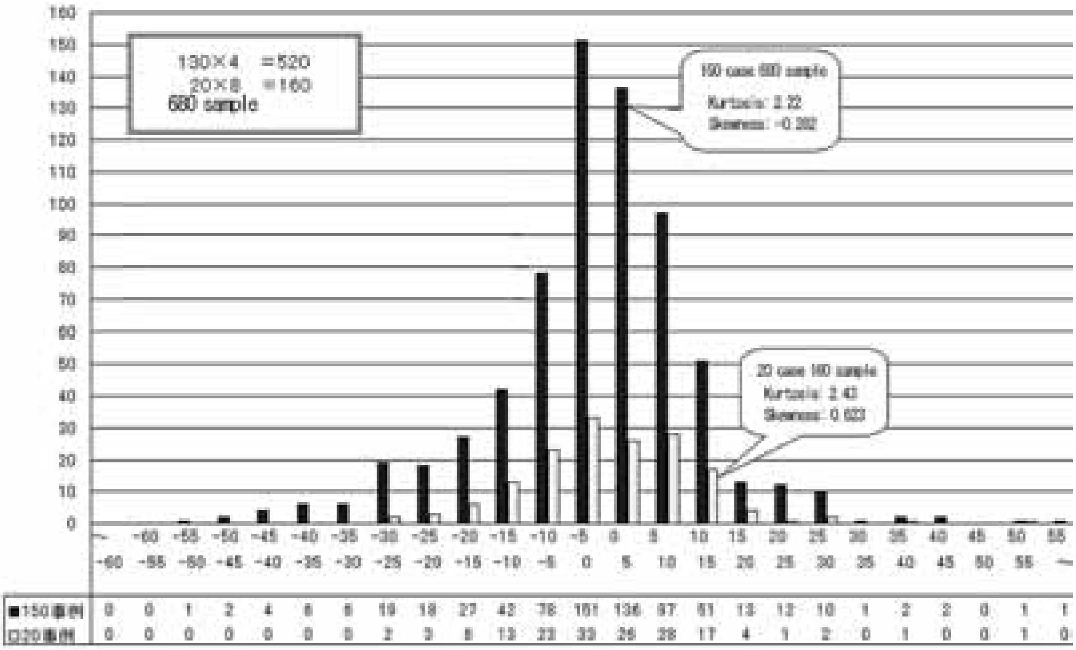


Fig. 7.5 Frequency distribution of the card score by inspectors.

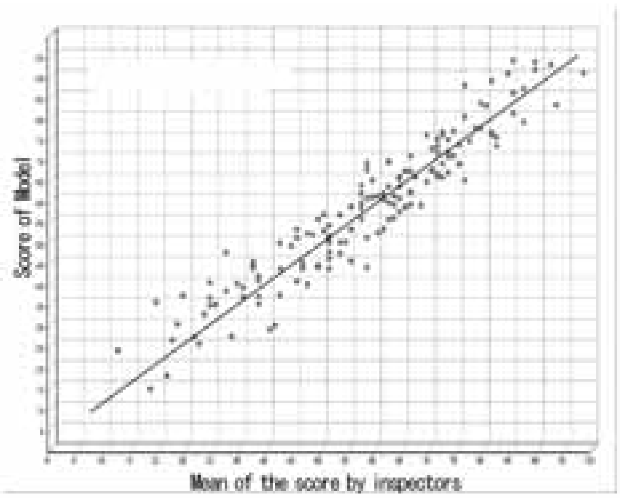


Fig. 7.6 Model of multi regression analysis.

classification is compared as a pair of items based on AHP. For convenience of the practice, the categories in **Fig.7.2** are arranged so as to increase the risk from the top to the down.

In the card, they are arranged from the left to the right, making possible to understand clearly the mechanisms of the formation of landform. Also, a category can be checked between some categories. For example, in the item F in **Fig.7.2**, if a category is judged as being between "Talus" and "Large talus", it is possible to check between these categories. However, if there is more than one category, the heavy one should be contributed to the calculation.

7.2.3 Comparison of a pair of items, the decision and unification of weight

At the work meetings, each member implemented the AHP evaluation as a basis for discussion, and then formed an AHP weight plan. The value of AHP is established as follows.

1: one item is almost as important as the other.
3: the former is a little important than the latter.
5: the former is important than the latter.
7: the former is considerably important than the latter.
(2, 4, 6 and 8 are used complementarily)

A number of literatures refer to the calculation process of the AHP. But here, we will not be concerned with the process. The final weight of each category should be calculated on the following formula.

Final weight of the categories in small classification = AHP weight of large classification × AHP weight of medium classification × AHP weight of small classification

In **Fig.7.2**, the coefficient as the value of items, if the highest one among the medium classification categories is checked, a revised coefficient is squared so as to find the total score be 100. In the card, the total amount of these check points is referred to as AHP score (the total amount of coefficient of weighted model). That is, AHP score $= \alpha \cdot \Sigma X$ (A-I) here, α : revised coefficient

7.2.4 Inspection recoad sheet marking and degree of agreement

At the work meetings, each member appended the cases in his card marking. The score of the card was intuitively calculated on the experiences of each member. The allotment is as follows.

There is every possibility of a landslide slip: 70-100
Unclear 30-70
There is little possibility of a landslide slip: 0-30
There is no possibility of landslide: ?

Collecting the card marking of each member, we defined

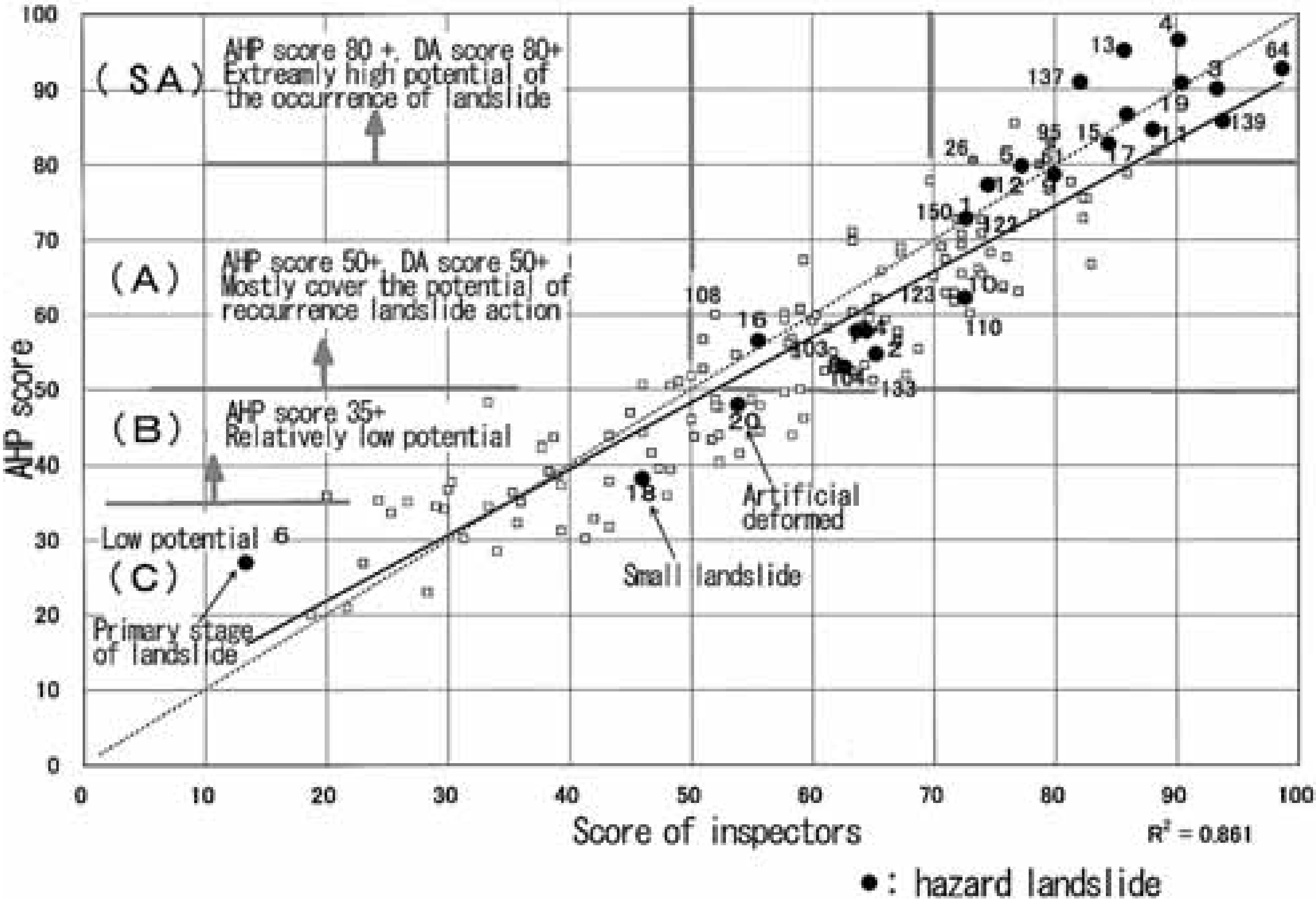


Fig. 7.7 Validity of the AHP model by the inspectors' valuation.

the degree of agreement (A), an index which determines this agreement, as follows.

Here, n is the numbers of each item (however, it contains 'unchecked' categories.) m is the mean value of the number of the anticipants at each category if the category checked by each members is 1.

The characteristics of the degree of agreement is that if each member checks different numbers, A=0, on the other hand, each member checks all the same point, the degree of agreement, A=1, indicating that all the members completely agreed.

As illustrated in **Fig.7.3**, each member freely appended in his card marking 10 cases among the above 20 as the case study of hazards (the third special meeting). As a result of this, a scatter was found at A-F and the discrepancy of each member's check point was clearly known. Based on this experience, we have formed a manual about the interpretation of micro landforms through the work meetings and clarified the points of identification about micro landform items. As a consequence, the remarkable raising of the degree of agreement was found in the card about 20 cases, which were added to the rest 10 cases. (the fourth special meeting).

Fig.7.4 shows a relation between the mean value of the card in 150 cases and the degree of agreement (A). The degree of agreement of samples in the card is the average mark of the degree of agreement of item A-I. As a result of this, it was shown that cases with high mean value in the card shows high degree of agreement. This will indicate that cases judged as 'having high probability' by landslide engineers basically show less gap in the checkpoints of card marking.

In **Fig.7.5**, each member's value of difference in the card marking, given by the mean value of the card, is shown on a frequency distribution (in units of 5 points). The early and latter working groups are shown as a histogram. It will be clear from this figure that each inspectors of the working groups has gradually got skillful in evaluation methodology and they have come to agreement.

7.2.5 Consideration about adequacy of the method

Considering the adequacy of evaluation of the probability based on AHP, we analyzed the positions of card marking（impediment variable）and the mean value of the card（dependent variable）of 150 cases, which were formed by 8 inspectors based on multivariate analysis. First, as for 20 cases of occurrence, the analysis based on the approach

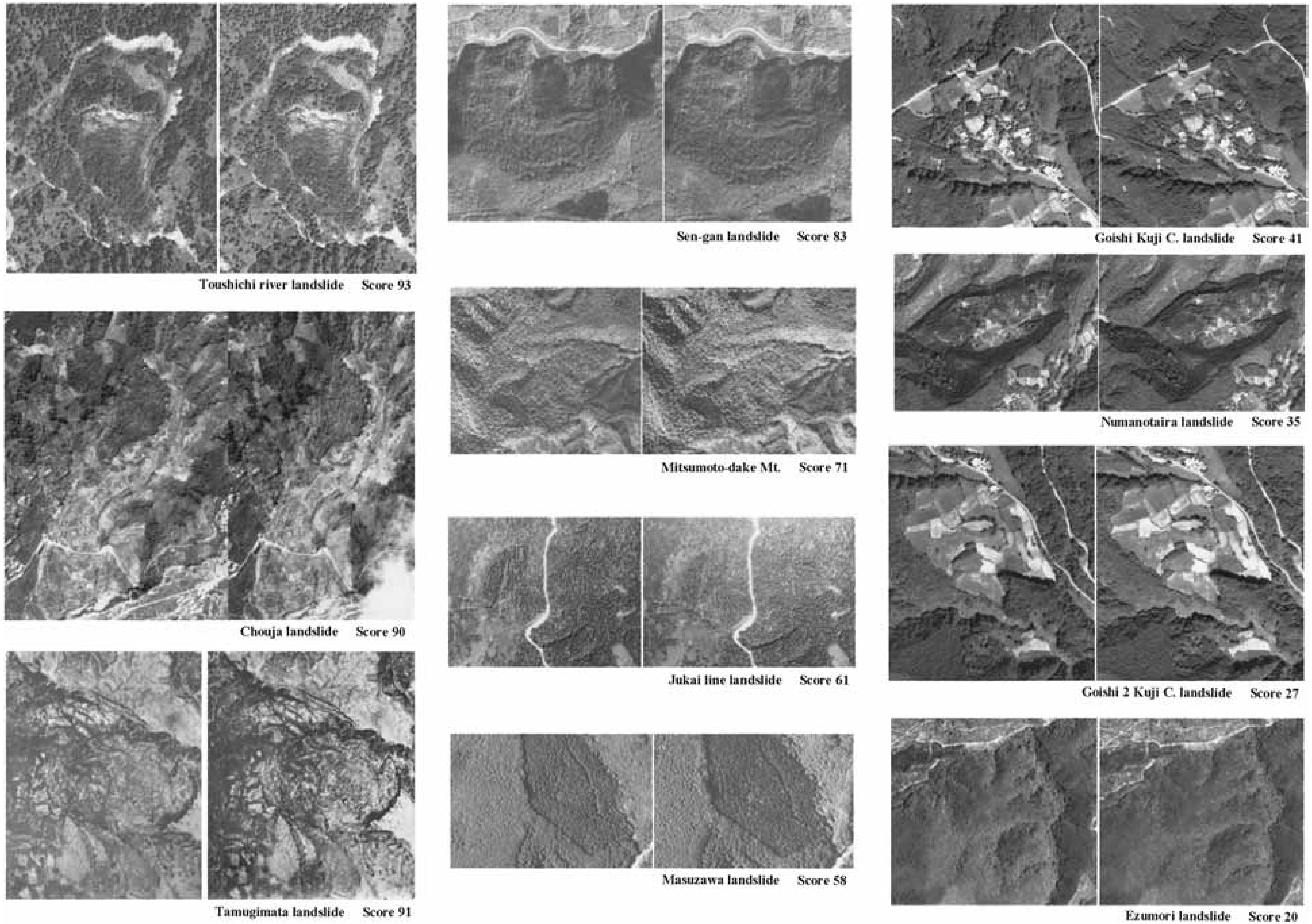


Fig. 7.8 Samples for standard of the AHP score landslide topographies.

of the quantificational method Ⅰ was implemented to the items whose degree of agreement were fully formed. As for 150 cases, they were analyzed based on multiple regression, for they are fixed and the mean value of the inspection sheet as dependent variable is numerical variable when we regard the check points of categories of 8 inspectors as explanatory variable. Quantification method Ⅰ shows that value F of items B, F and L is over 2 and the ratio of contribution is over 0.75. On the other hand, as shown in **Fig.7.6**, it is possible to make a prospect model whose ratio of contribution is 0.08. On the basis of this result, a model formula, that is, the relation between **Fig.7.7**, which shows the score of the AHP (total score of model weights efficient), and the mean value of card was introduced by modifying the AHP plan having formed in the inspectors working groups.

7.3 Adaptability of AHP

Fig.7.7 shows that the standard (special A-C) was formed in the introduction of this model and that the adequacy of this model was confirmed on the cases of landslide occurrence. However, through this research, it was made clear that the preparation of some manual and the time to acquire the skills will be necessary to improve the skill of the aerial photo interpretation. Thus, we hope that a technical guideline of aerial photo interpretation will be made in the future based on this model.

8. Conclusive remarks

The project developed the manual and inspection record sheet for the systematic risk evaluation of the landslide reoccurrence on the landslide topography through aerial photo interpretation. The manual is applying to several other prefectures.

The project of the "landslide topography distribution map by photo interpretation" is covered 60% of all the country in Japan now. The real distribution of landslide topography will be clarified in the near future. It means that the risk evaluation of the landslide topography is quite important for risk management. The risk evaluation is not only means for the probability of landslide re-action but also some kind of geological characteristics of landslide area in geomorphologic.

The manual and evaluation is only useful for the basic risk evaluate ion data. The purpose of evaluation is to select the target landslide among a number of landslide topography. The field investigation should be carried out based on this evaluation. So to speak this is the 1st stage screening for landslide hazard prevention.

The manual, mentioned samples and inspection record sheet should be improved and be replaced with more suitable one.

Acknowledgement

This report is based on the project of landslide topography mapping by National Disaster Prevention Research Center and the project of landslide risk evaluation by aerial photo interpretation in Iwate prefecture by Iwate Prefecture office and Japan Landslide Society. To tell the truth, the AHP and inspection work for landslide risk evaluation were hard work. The authors like to say thanks to all inspectors.

Finally I would like to say acknowledge to Miss Y. Ohashi for her kind assistance to completion of the English manuscript.

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(Accepted : April 22, 2004)

空中写真判読および AHP 法による地すべり地形の危険度評価手法の作成

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要　旨

防災科学技術研究所のプロジェクト（1982 年から開始され現在も継続中）などによって，地すべり地形の分布情報が全国的に完備される状況が目前に迫っている．全国の地すべり地形の所在を明らかにする過程で明らかになったことは，１）地すべり活動に起源を持つ地すべり地形領域の分布は全国的に極めて広範且つ多数に上ること．２）地質条件に対応した顕著な偏在傾向を有すること．３）地すべり災害との関連が想定され，その実例も多いものの，無数と言って良いほどに存在する地すべり地形の全てが，近未来に地すべり災害を引き起こすか否かは解らないことなどである．この地すべり地形の把握は，もっぱら空中写真の判読によって実行されているものである．同時にこの判読の過程では，地すべり活動の特性を把握するための多くの知見が得られ，その一部は現場の地すべり災害評価や調査の指針を作成する際に利用されている．

この報告では，これまでの判読技術を踏まえて，空中写真判読の技法を厳密且つシステマティックに適用し，個々の地すべり地形を構成する微地形と呼ばれる細部にわたる構造を，判読アイテムとして個別に判読評価し，そのアイテムが有する地すべり再活動への寄与の度合いを AHP 法を用いて重み付けを行い，それを総括して地すべり地形が有する再活動の危険度を定量的に把握しようとするものである．現実的には，地すべり災害を防止するために精査されるべきターゲットを特定するための技法とも言える．

この手法を構成する柱の一つが写真判読であることは既に述べたが，同時にこの手法では，現場の地すべり技術者が蓄積した経験則の様式化を行って，経験則にも見合う手法が確立されるべき工夫が施されている．その基本的なコンセプトは，個々バラバラの経験履歴を有する技術者達が有する「暗黙知」を「定式知」に変える作業である．地すべりと地すべり地形に関する共通認識を得るために，同じターゲットの写真判読を素材に議論することで，地すべり地形の危険度評価に関する考え方や着眼に一定の合意を得て，このような危険度評価手法が創り上げられた．本報告は，（社）日本地すべり学会が岩手県県土整備部から受託したプロジェクトを土台としているが，この技法が地すべり災害に直面する諸外国に広く応用され更に改良されてゆくことを願っている．

キーワード：地すべり，危険度評価，AHP 法，空中写真判読，危険度評価カルテ